Technical Report CHL-98-28
September 1998

US Army Corps
of Engineers
Waterways Experiment
Station

Design for Navigation Improvements at Nome Harbor, Alaska

Coastal Model Investigation

by Robert R. Bottin, Jr., Hugh F. Acuff

Prepared for U.S. Army Engineer District, Alaska

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Waterways Experiment Station
3909 Halls Ferry Road
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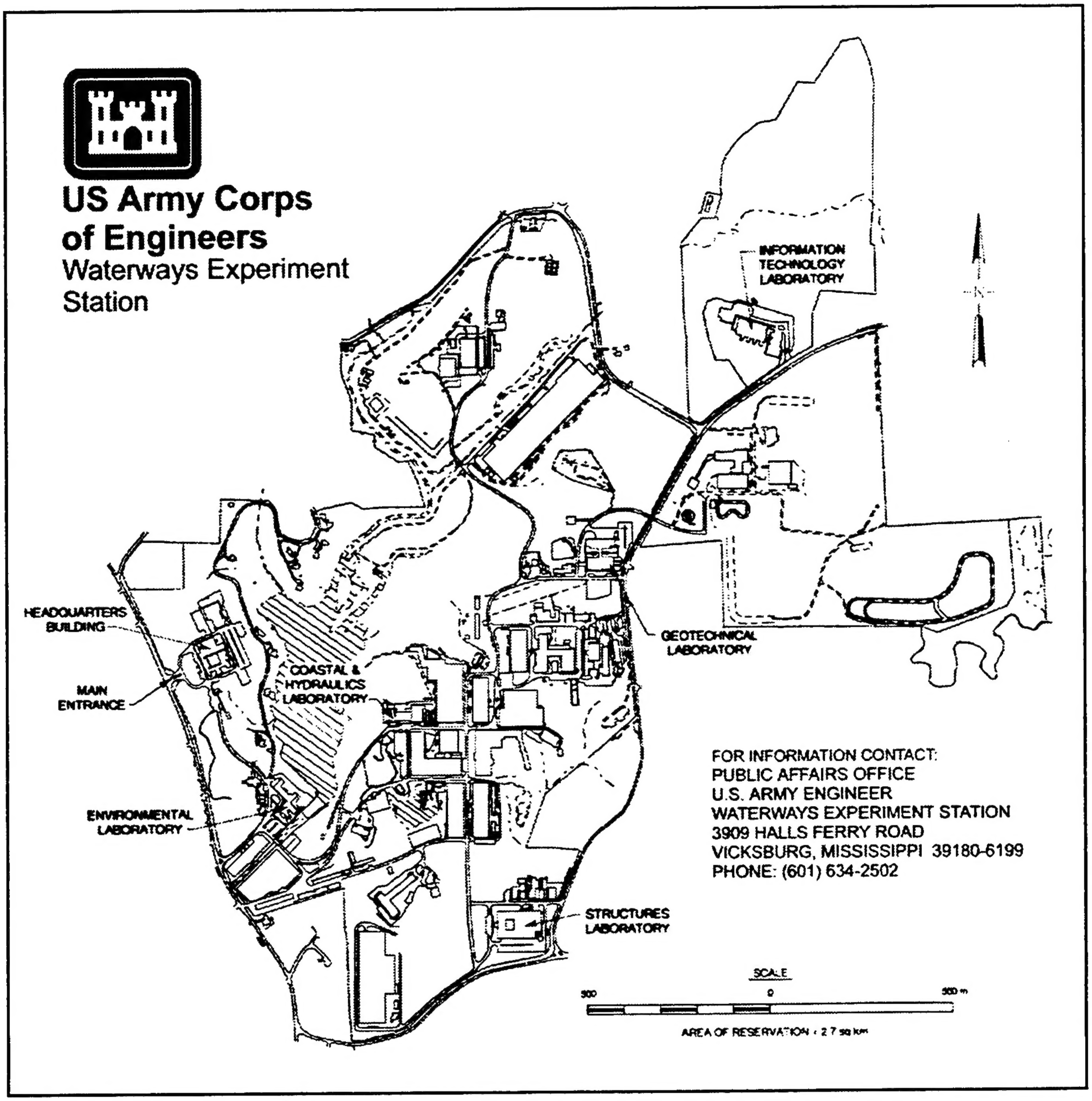
Final report

Prepared for U.S. Army Engineer District, Alaska
Anchorage, Alaska 99506-0898



Waterways Experiment Station Cataloging-in-Publication Data

Bottin, Robert R.
Design for navigation improvements at Nome Harbor, Alaska : coastal model investigation / by Robert R. Bottin, Jr., Hugh F. Acuff ; prepared for U.S. Army Engineer District, Alaska.
153 p. : ill. ; 28 cm. — (Technical report ; CHL-98-28)
Includes bibliographic references.
1. Harbors — Alaska — Nome — Models. 2. Navigation — Alaska — Nome — Models. 3. Hydraulic models. I. Acuff, Hugh F. II. United States. Army. Corps of Engineers. Alaska District. III. U.S. Army Engineer Waterways Experiment Station. IV. Coastal and Hydraulics Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; CHL-98-28.
TA7 W34 no.CHL-98-28

Contents

Preface

A request for a model investigation to study navigation improvements at Nome Harbor, Alaska, was initiated by the U.S. Army Engineer District, Alaska, in a letter to the U.S. Army Engineer Division, Pacific Ocean. Headquarters, U.S. Army Corps of Engineers (HQUSACE) subsequently authorized the U.S. Army Engineer Waterways Experiment Station (WES), Coastal and Hydraulics Laboratory (CHL), to perform the study. Funds were provided by the Alaska District on 4 August 1997, 14 October 1997, 9 January 1998, and 27 February 1998.

Model experiments were conducted at WES during the period December 1997 through March 1998 by personnel of the Harbors and Entrances Branch (HEB) of the Navigation and Harbors Division (NHD), CHL, under the direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director of CHL, respectively; and under the direct guidance of Messrs. C. E. Chatham, Jr., Chief of NHD; and Dennis G. Markle, Chief of HEB. Model experiments were conducted by Messrs. Hugh F. Acuff and Larry R. Tolliver, Civil Engineering Technicians, and William G. Henderson, Computer Assistant, under the supervision of Mr. Robert R. Bottin, Jr., Research Physical Scientist. This report was prepared by Messrs. Bottin and Acuff. Word Processing and formatting were completed by Ms. Myra E. Willis, CHL.

Prior to the model investigation, Messrs. Bottin and Acuff met with represenatatives of the Alaska District and visited Nome Harbor to inspect the prototype site. During the course of the study, liaison was maintained by means of conferences, telephone communications, E-mail, and monthly progress reports. Messrs. Ken Eisses and Ed Sorenson were technical points of contact for the Alaska District. The following personnel visited WES to attend briefings, conferences, and/or observe model operation during the course of the study.

Mr. Let Mon Lee	HQUSACE
Mr. Henri Langlois	HQUSACE
Mr. Jim Nakasone	Pacific Ocean Division
Mr. Carl Stormer	Alaska District
Mr. Ken Eisses	Alaska District
Mr. Ed Sorenson	Alaska District
Mr. John Burns	Alaska District
Mr. Will Appleton	Alaska District

Mr. Ken Boire	Consulting Economist, Alaska District
Mr. John Oliver	Engineering Consultant, Alaska District
Mr. John Handeland	Mayor, City of Nome
Mr. Mike Yanez	City Manager, City of Nome
Mr. Stan Andersen	City Council, City of Nome
Mr. Norman Johnson	City Council, City of Nome
Mr. Terry Wilson	Harbor Commission, City of Nome
Mr. Randy Romenesko	City Engineer, City of Nome
Mr. Don Stultz	President, Nome Planning Commission
Mr. Paul Fuhs	Consultant, City of Nome

Dr. Robert W. Whalin was Director of WES during model experimentation and the preparation and publication of this report. COL Robin R. Cababa, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic meters per second
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet per second	0.3048	meters per second
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
pounds (mass)	0.4536	kilograms
square feet	0.09290304	square meters
square miles (US statute)	2.589988	square kilometers
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Prototype

Nome is located on the Seward peninsula in western Alaska (Figure 1). It is known as the transportation and commercial center for northwest Alaska. Nome is accessible only by air and water, and cannot be reached by road from any major city. A local road system leads to three small neighboring villages. Mining, fishing, and tourism are the major industries in Nome.

Nome Harbor is located on the Norton Sound, Bering Sea, at the mouth of the Snake River. The original Federal project, authorized in 1917, was among the first Corps of Engineers navigation projects in Alaska. It provided for a 102-m-long (335-ft-long)[1] east jetty, a 140-m-long (460-ft-long) west jetty, and a 2.44-m-deep[2] (8-ft-deep), 23-m-wide (75-ft-wide), 587-m-long (1,925-ft-long) entrance channel extending from Norton Sound to a turning basin up the Snake River. The basin was 2.44 m deep (8 ft deep) and approximately 76 m by 183 m (250 ft by 600 ft) in area. Dredging of the channel and basin were completed in 1922. Construction of the jetties (originally concrete and timber structures) was completed in 1923. In addition, approximately 1,163 linear m (3,815 linear ft) of steel sheet-pile wall was constructed that lined the entrance channel and eastern side of the turning basin.

Due to extensive ice and storm damage, the east and west jetties were reconstructed (with concrete and steel) in 1940 to modified lengths of 73 m (240 ft) and 122 m (400 ft), respectively. The east jetty was repaired in 1954, and both were again repaired in 1965. Emergency repairs to the steel sheet-pile wall were accomplished in 1985 and 1986 (U.S. Army Engineer District, Alaska (USAEDA) 1996). The existing federal project is shown in Figure 2.

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[1] Units of measurement in the main text of this report are shown in SI (metric) units, followed by non-SI (British) units in parentheses. In addition, a table of factors for converting non-SI units of measurement used in figures, plates, and tables in this report to SI units is presented on page vi.

[2] All depths and elevations cited herein are in meters (feet) referred to mean lower low water (mllw) unless otherwise noted.

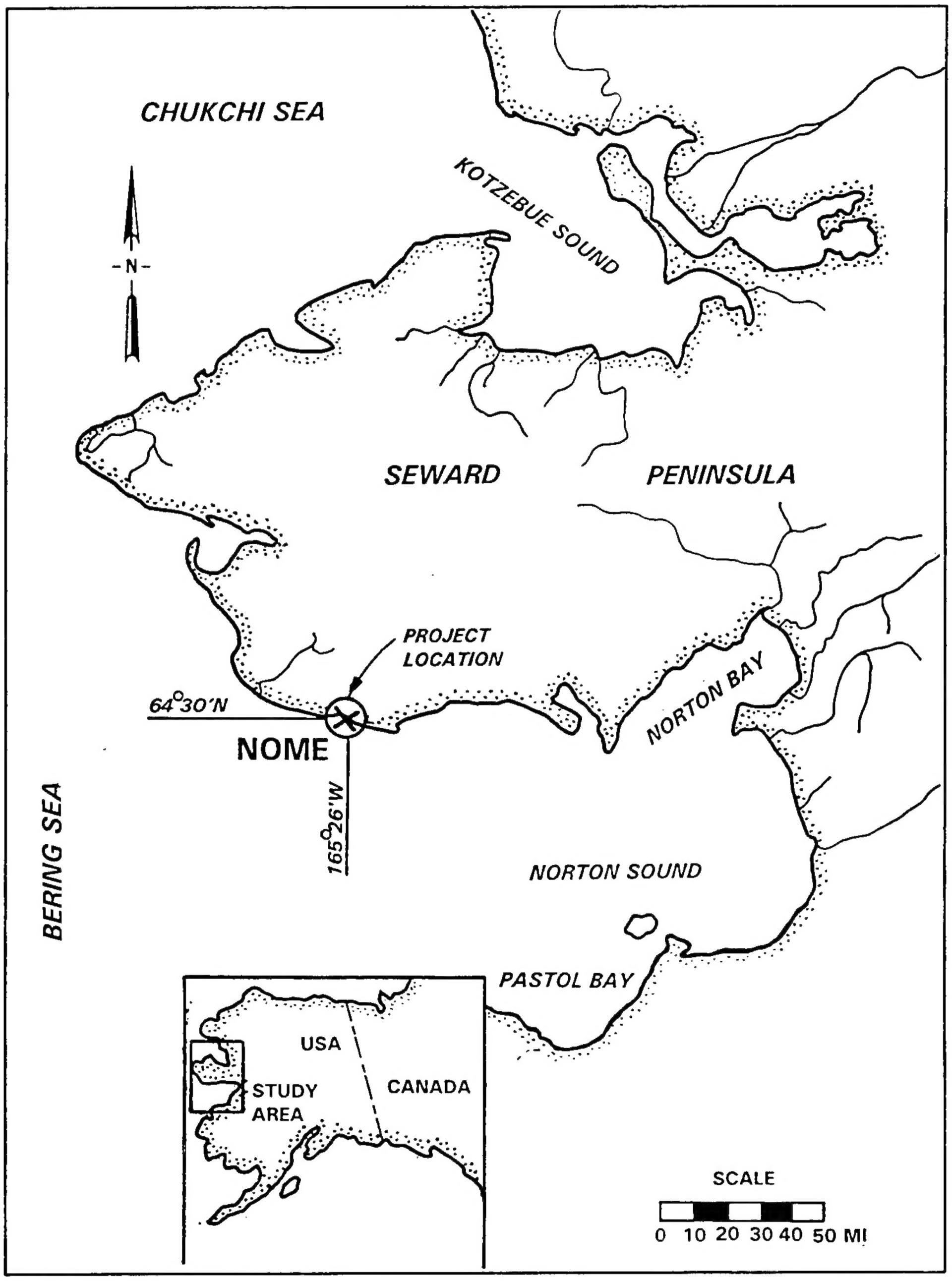

Figure 1. Project location

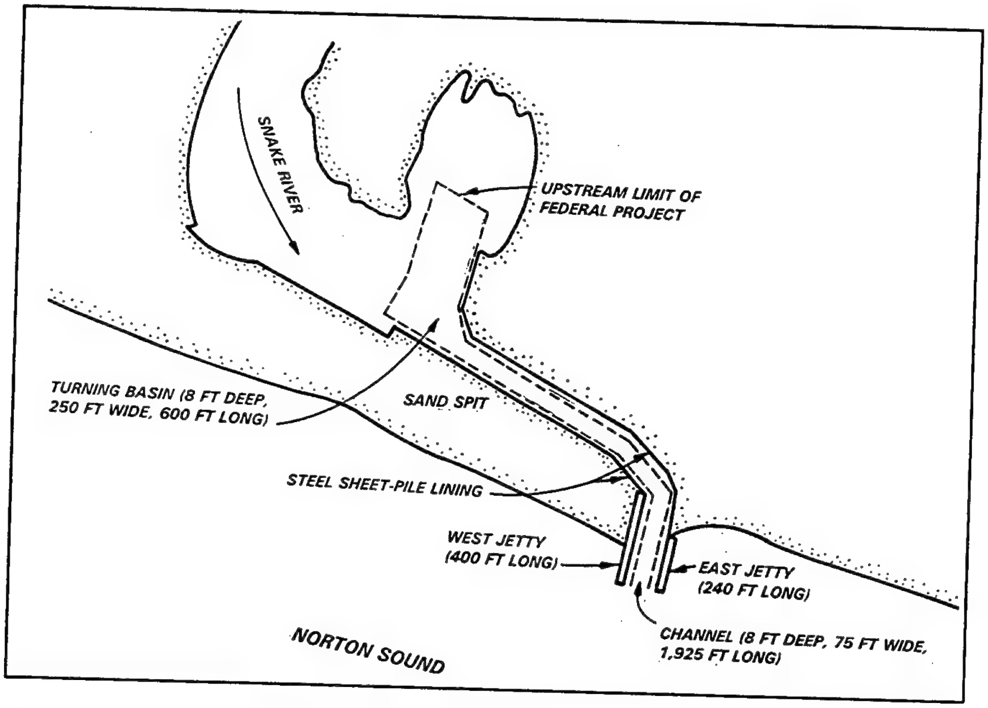

Figure 2. Existing Nome Harbor Federal project

An 823-m-long (2,700-ft-long) causeway, constructed in the mid-1980's, extends into the Norton Sound west of the harbor entrance. It is a rubble-mound structure that includes two vertical sheet-pile docks on the east side for vessel off-loading and berthing. The facilities were designed and built for cargo and petroleum vessels of 122 m (400 ft) in length and greater, and cruise ships that load and unload passengers. The depth at the causeway outer dock facilities is about 6.3 m (20 ft) and 4.3 m (14 ft) at the inner dock. A breach in the causeway, close to its shoreward end, allows nearshore water flow for fish migration and shoreline accessibility for small boats. The design depth through the breach is -2.4 m (-8 ft). A 1997 field survey, however, indicated depth of about -0.76 m (-2.5 ft). A stone revetment is located along the shoreline east of the existing harbor entrance. A federally constructed 1,020-m-long (3,350-ft-long) revetment was completed in 1951 to protect the shoreline from erosion. The State of Alaska constructed a 1,143 m (3,750 ft) eastern extension, which was completed in 1995. Figure 3 is an aerial photo of Nome Harbor.

Problems and Needs

Maintenance requirements for the existing harbor facilities are high. Maintenance is performed almost every year on the entrance jetties, the sheet-pile walls, and the turning basin (dredging). The existing project is currently in dire need of repair, with major rehabilitation required within the next year. In addition, vessel damages are caused by the hydraulic characteristics of the current entrance channel. Large waves propagate unimpeded through the channel, creating a significant hazard to small craft. Larger vessels impact the sheet-pile walls at the sharp turn in

Figure 3. Aerial view of Nome Harbor

the entrance channel, which causes vessel damage as well as damage to the sheet pile.

The existing project has become inadequate to meet the needs of the current fleet, due in part to the growth in the local fishing industry. Fisheries' management changes and increasing interest in the fishing industry have changed the fishing fleet in Norton Sound. The fleet, once composed solely of large fish processors that did not stop in Nome, is now composed of mostly 9.8-m-long (32-ft-long) vessels, which must frequently use the harbor. Barge lightering operations in Nome are also different from when the project was constructed, and barge operators are increasingly burdened by the narrow, sharp-bended, entrance channel configuration. Nome needs expanded moorage facilities to accommodate the increased number of commercial vessels using the harbor. Current facilities in the area are crowded, inadequate, and sometimes unsafe. Vessels currently incur damages due to grounding and bumping against the sheet pile or each other.

In summary, there are multiple purposes for navigation improvements at Nome Harbor. Improvements would (a) provide a safer harbor with more efficient access for the design fleet; (b) provide additional moorage for small fishing vessels, tugs, and barges; and (c) reduce operation and maintenance costs (USAEDA 1996).

Purpose of the Model Investigation

At the request of the U.S. Army Engineer District, Alaska , a coastal hydraulic model investigation of Nome Harbor was initiated by the U.S. Army Engineer Waterways Experiment Station (WES) to accomplish the following:

a. Study wave, current, and shoaling conditions for the existing harbor configuration.

b. Determine the impacts of a new entrance channel and harbor configuration on wave-induced current patterns and magnitudes, sediment transport patterns, and wave conditions in the new channel and mooring area.

c. Optimize the length and alignment of a new breakwater structure required to provide adequate protection.

d. Optmize the length and alignment of causeway extensions, in conjunction with the new breakwater, to provide adequate protection for waves and currents and minimize shoaling problems.

e. Develop remedial plans for the alleviation of undesirable conditions as necessary.

f. Determine if the proposed design could be modified to significantly reduce construction costs without sacrificing the desired level of protection.

2 The Model

Model Design

The Nome Harbor model (Figure 4) was constructed to an undistorted linear scale of 1:90, model to prototype. Scale selection was based on the following factors:

a. Depth of water required in the model to prevent excessive bottom friction.

b. Absolute size of model waves.

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Available wave-generating and wave-measuring equipment.

f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Model-Prototype Dimension[1]	Scale Relations
Length	L	L_r = 1:90
Area	L^2	$A_r = L_r^2$ = 1:8,100
Volume	L^3	$V_r = L_r^3$ = 1:729,000
Time	T	$T_r = L_r^{1/2}$ = 1:9.49
Velocity	L/T	$V_r = L_r^{1/2}$ = 1:9.49
Discharge	L^3/T	$Q_r = L_r^{5/2}$ = 1:76,818

[1]Dimensions are in terms of length (L) and time (T).

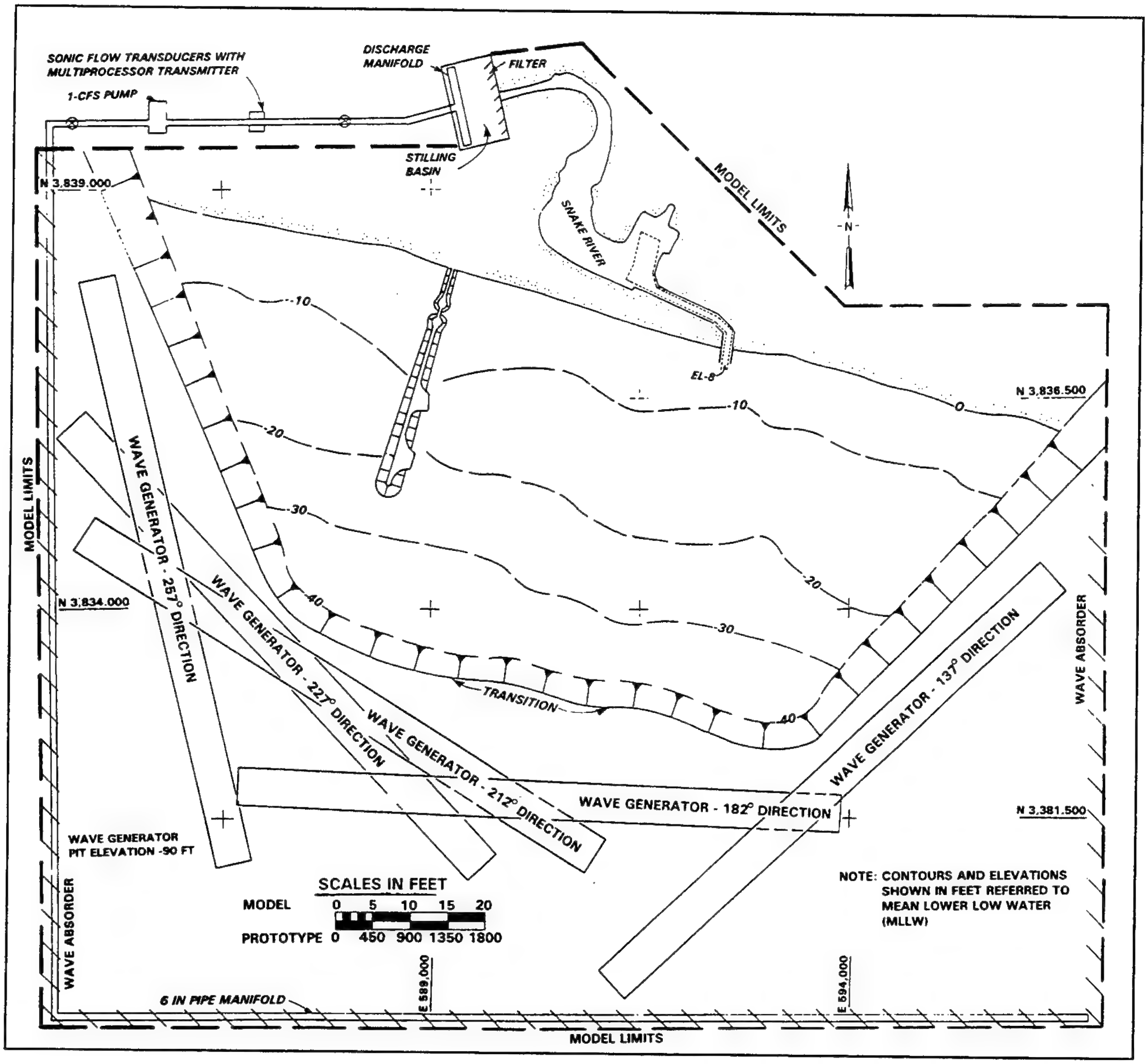

Figure 4. Model layout

The existing causeway and revetment adjacent to Nome Harbor, as well as the proposed jetties and breakwaters, are rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, the transmission, reflection, and absorption of wave energy became a matter of concern in the design of a 1:90-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (LéMehauté 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, small-scale model rubble-mound structures must be adusted somewhat to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations (Dai and Jackson 1966, Brasfeild and Ball 1967) at WES, this adjustment was made by determining wave-

energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A cross section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission and reflection of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at Nome Harbor, it was determined that the correct wave-energy transmission and reflection characteristics could be closely approximated by increasing the size of the rock used in the 1:90-scale model to approximately two times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the Nome Harbor model, rock sizes were computed linearly by scale, then multiplied by 2 to determine the actual sizes to be used in the model.

Ideally, a quantitative, three-dimensional, movable-bed model investigation would best determine the impacts of harbor modifications with regard to sediment deposition in the vicinity of the harbor. However, this type of model investigation is difficult and expensive to conduct, and each area in which such an investigation is contemplated must be carefully analyzed. In view of the complexities involved in conducting movable-bed model studies and due to limited funds and time for the Nome Harbor project, the model was molded in cement mortar (fixed-bed), and a tracer material was obtained to qualitatively determine sediment patterns in the vicinity of the harbor.

Model and Appurtenances

The model reproduced approximately 3,350 m (11,000 ft) of the Alaskan shoreline, the existing harbor and lower reaches of the Snake River, and underwater topography in the Norton Sound to an offshore depth of 12.2 m (40 ft) with a sloping transition to the wave generation pit elevation of -27.4 m (-90 ft). The total area reproduced in the model was approximately 1,225 sq m (13,200 sq ft), representing about 9.8 sq km (3.8 sq miles) in the prototype. Vertical control for model construction was based on mean lower low water (mllw), and horizontal control was referenced to a local prototype grid system. Figure 5 is a general view of the model.

Model waves were reproduced by a 24.4-m-long (80-ft-long), electrohydraulic, unidirectional spectral wave generator with a trapezoidal-shaped, vertical motion plunger. The wave generator utilized a hydraulic power supply. The vertical motion of the plunger was controlled by a computer-generated command signal, and movement of the plunger caused a displacement of water, which generated the required experimental waves. The wave generator also was mounted on retractable casters, which enabled it to be positioned to generate waves from the required directions.

An Automated Data Acquisition and Control System, designed and constructed at WES (Figure 6), was used to generate and transmit wave generator control signals, monitor wave generator feedback, and secure and analyze wave data at selected locations in the model. Through the use of a Microvax computer, the electrical output of parallel-wire, capacitance-type wave gauges, which varied with

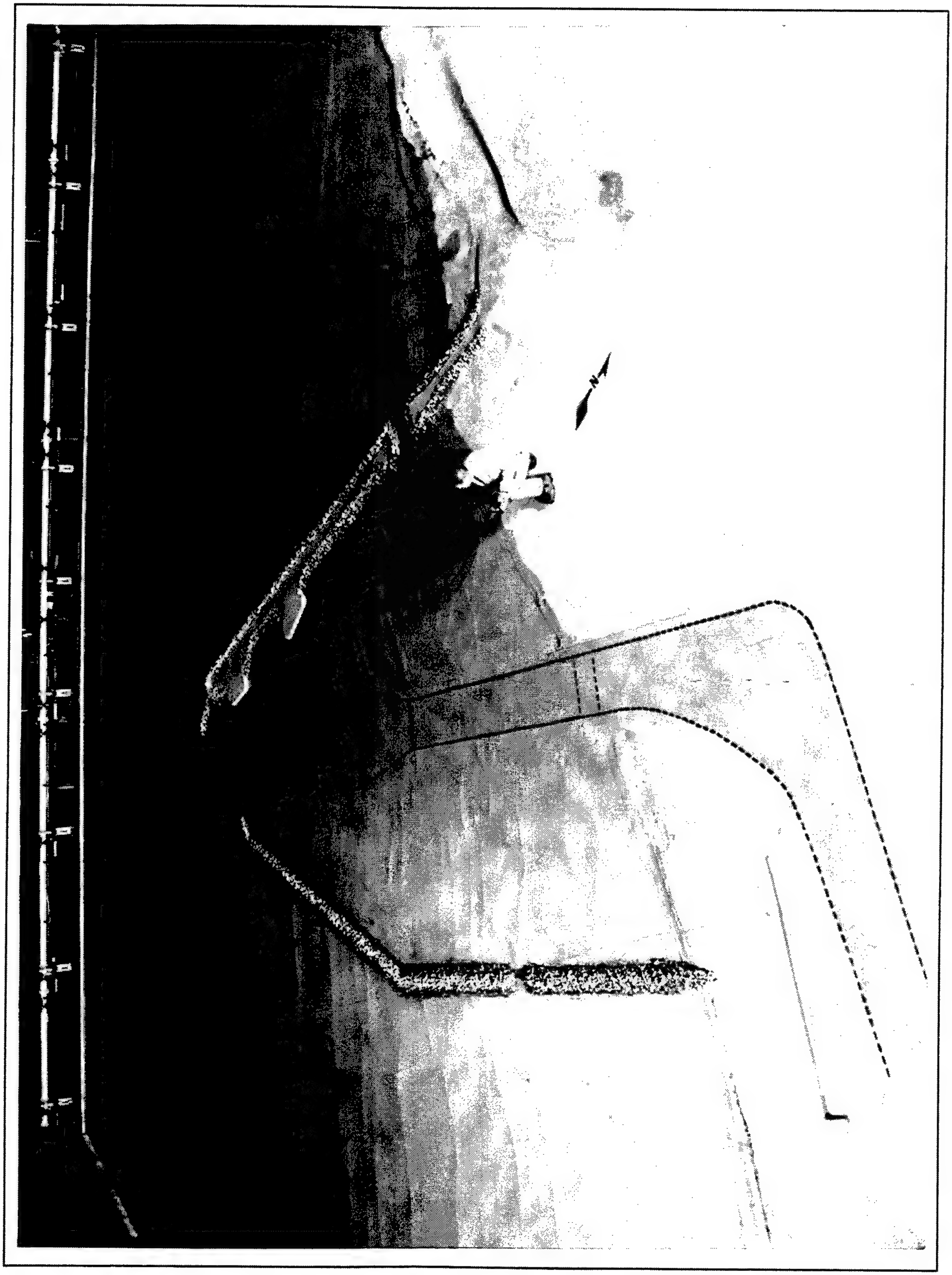

Figure 5. General view of model

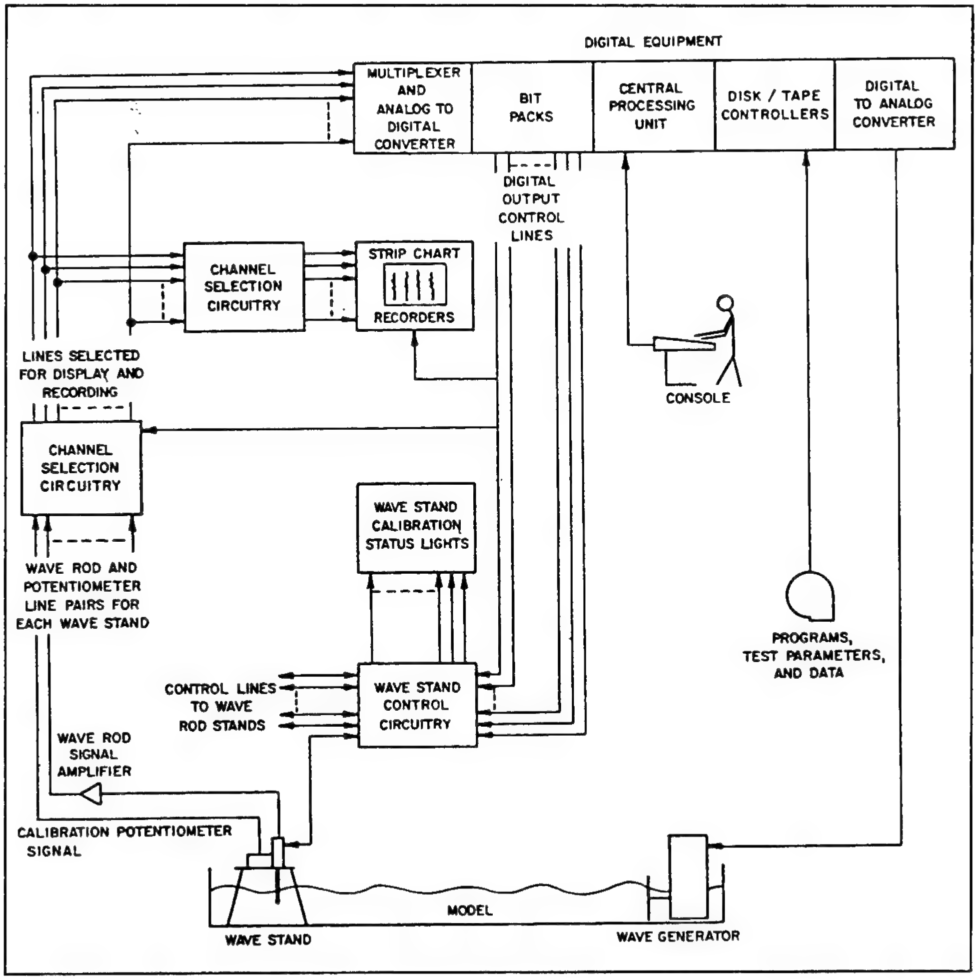

Figure 6. Automated Data Acquisition and Control System

the change in water-surface elevation with respect to time, were recorded on magnetic disks. These data then were analyzed to obtain the parametric wave data.

A water circulation system (Figure 4), consisting of a 15.2-cm (6-in.), perforated-pipe water-intake manifold, a 0.03-cms (1-cfs) pump, and sonic flow transducers with a multiprocessor transmitter, was used in the model to reproduce steady-state flows through the Snake River that corresponded to selected prototype river flows. The magnitudes of river currents were measured by timing the progress of weighted floats over known distances.

A 0.6-m (2-ft) (horizontal) solid layer of fiber wave absorber was placed along the inside perimeter of the model to dampen wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

Design of Tracer Material

As discussed previously, a fixed-bed model was constructed and a tracer material selected to qualitatively determine movement and deposition of sediment in the vicinity of the harbor. Tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation, or model law, among the four basic scale ratios, i.e., the horizontal scale λ ; the vertical scale μ ; the sediment size ratio η_D ; and the relative specific weight ratio η_γ. These relations were determined experimentally using a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone.

Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:90 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of Nome Harbor was undistorted to allow accurate reproduction of short-period wave and current patterns, the following procedure (which has been successfully used and validated for undistorted models) was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.15 mm, specific gravity = 2.7) and assuming the horizontal scale to be in similitude (i.e., 1:90), the median diameter for a given vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented the movement of prototype sand. Therefore, quantities of crushed coal (specific gravity = 1.30; median diameter, D_{50} = 0.29 - 0.54 mm) were selected for use as a tracer material throughout the model investigation.

3 Experimental Conditions and Procedures

Selection of Experimental Conditions

Still-water level

Still-water levels (swl's) for wave action models are selected so that various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include refraction of waves in the project area, overtopping of harbor structures by waves, reflection of wave energy from various structures, and transmission of wave energy through porous structures.

In most cases, it is desirable to select a model swl that closely approximates the higher water stages that normally occur in the prototype for the following reasons:

a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.

b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind, tide, and storm surge.

c The selection of a high swl helps minimize model scale effects due to viscous bottom friction.

d. When a high swl is selected, a model investigation tends to yield more conservative results.

Swl's of +0.5 and +4.0 m (+1.6 and +13.0 ft) were selected by the Alaska District for use during the model experiments. The lower value (+0.5 m (+1.6 ft)) represents mean higher high water (mhhw) and was used while obtaining wave heights, wave-induced current patterns and magnitudes, and sediment tracer patterns in the vicinity of the harbor and causeway. The higher value (+4.0 m (+13.0 ft)) represented extreme storm surge conditions and also was used for selected directions while securing wave height data, current patterns and magnitudes, and

sediment tracer patterns. This value was estimated at the harbor based on observations made in the prototype during storm wave conditions. Intermediate swl's of +1.2 and 2.4 m (+4.0 and +8.5 ft) were selected for limited experiments during preliminary testing.

Factors influencing selection of experimental wave characteristics

In planning the experimental program for a model investigation of harbor wave-action problems, it is necessary to select heights, periods, and directions for the experimental waves that will allow a realistic study of the proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum significant wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, and the distance over water (fetch) which the wind blows. Selection of experimental wave conditions entails evaluation of such factors as:

a. Fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can approach the problem area.

b. Frequency of occurrence and duration of storm winds from the different directions.

c. Alignment, size, and relative geographic position of the navigation structures.

d. Alignments, lengths, and locations of the various reflecting surfaces in the area.

e. Refraction of waves caused by differentials in depth in the area seaward of the site, which may create either a concentration or a diffusion of wave energy.

When waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to selection of experimental wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. For this study, the Alaska District utilized numerical wave transformation models to transform deepwater wave characteristics into shallow-water values. The transformation models included refractive, diffractive, and shoaling effects of the offshore bathymetry. Shallow-water wave characteristics were obtained at the -12.2-m (-40-ft) contour, which corresponded to the approximate wave generator location in the physical model.

Wave hindcast data and selection of experimental waves

Measured prototype data covering a sufficiently long duration from which to base a comprehensive statistical analysis of wave conditions were unavailable for the Nome Harbor area. However, a wave hindcast study was developed based on wind data in the area to define the wave climate (Applied Coastal Modeling 1997) at the Nome Harbor site. The objective of the hindcast was to define the general range of wave heights, periods, directions, and frequencies of occurrence at the project site. In general, the study indicated a relatively moderate wave climate at Nome with wave periods 12 sec or less, and heights 2 m (6.6 ft) or less occurring about 95 percent of the time (when waves are present). Waves up to 6 m (19.7 ft) in height, however, may occur on a 50-year recurrence interval. In addition, the study indicated that waves approach from a southwesterly sector about 66 percent of the time (when waves are present). Model experiments were actually initiated prior to completion of the hindcast study. The Alaska District initially selected the following wave conditions for use in the model investigation, which cover a large range of wave directions, periods, and heights. However, upon completion of the hindcast, the number of wave conditions was reduced.

Unidirectional wave spectra were generated based on Joint North Sea Wave Project (JONSWAP) parameters for the selected waves and used throughout the model investigation. Typical wave spectra are shown in Figure 7. The solid line represents the desired spectra, while the dashed line represents the spectra reproduced in the model. Figure 8 is a typical wave train time series. Selected waves were defined as significant wave height, the average height of the highest one-third of the waves or H_s. In deep water, H_s is very similar to H_{mo} (energy-based wave) where $H_{mo} = 4\ (E)^{1/2}$, and E equals total energy in the spectra, which is obtained by integrating the energy density spectra over the frequency range.

River discharges

The Snake River runs generally southerly from the mountains and turns easterly near the Norton Sound coast. It flows through the currently authorized turning basin and the existing sheet-pile-lined navigation channel into Norton Sound. The mean annual discharge measured by the U.S. Geological Survey is 5.4 cms (190 cfs) northeast of Nome (USAEDA 1996). The typical maximum monthly mean flow occurs in June following the spring snowmelt. After the summer rains, progressively lower discharge peak flows occurs, and discharge continues to decline through the winter. During the period 1965-1991, the Snake River's maximum monthly mean discharge was 47 cms (1,655 cfs). The mean annual discharge of 5.4 cms (190 cfs) was selected for use during all model experiments.

Wave Conditions		
Direction, Azimuth	**Period, sec**	**Height, m (ft)**
257	12	6 (19.7)
	24	3 (9.8)
227	9	1 (3.3) 2 (6.6)
	12	1 (3.3) 2 (6.6) 3 (9.8) 5 (16.4) 6 (19.7
	24	3 (9.8)
212	9	1 (3.3) 2 (6.6) 3 (9.8)
	12	1 (3.3) 2 (6.6) 3 (9.8)
	15	1 (3.3) 2 (6.6) 3 (9.8)
	24	1 (3.3) 2 (6.6) 3 (9.8)
182	9	1 (3.3) 2 (6.6) 3 (9.8)
	12	1 (3.3) 2 (6.6) 3 (9.8) 5 (16.4) 6 (19.7)
	15	1 (3.3) 2 (6.6) 3 (9.9)
	24	1 (3.3) 2 (6.6) 3 (9.8)
137	9	1 (3.3) 2 (6.6)
	12	1 (3.3) 2 (6.6) 3 (9.8) 5 (16.4) 6 (19.7)
	24	3 (9.8)

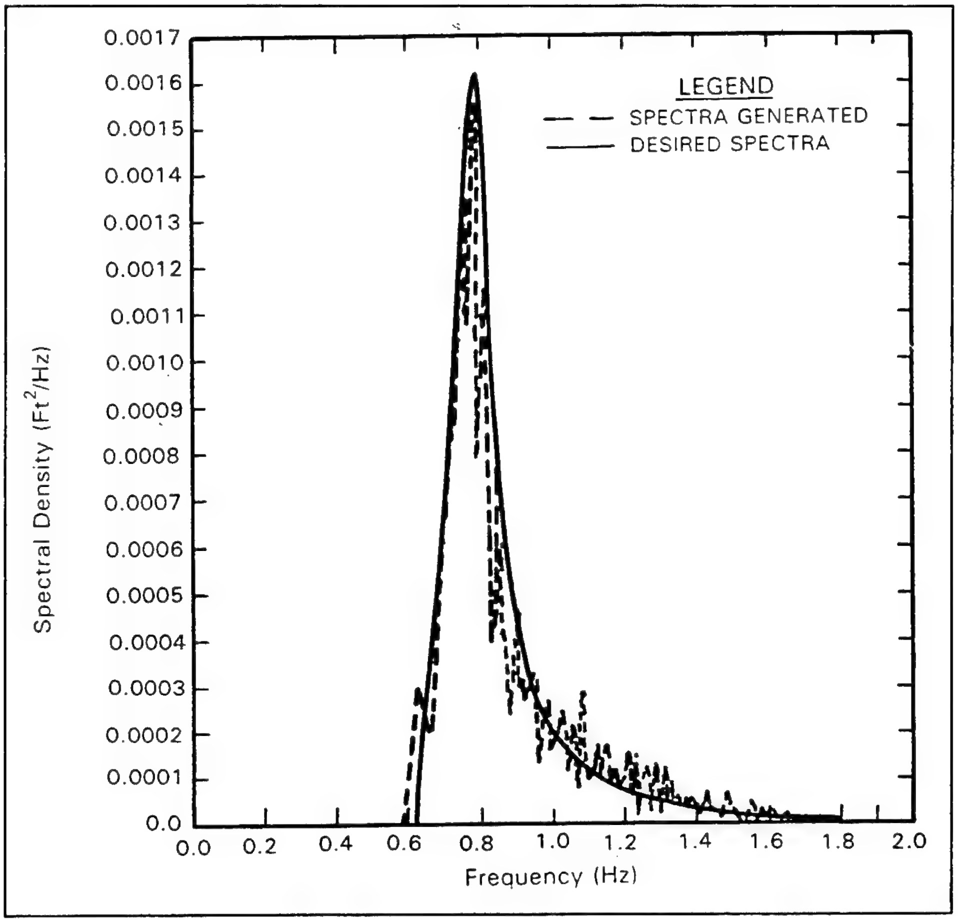

Figure 7. Typical energy density-versus-frequency plots (model terms) for a wave spectra; 12-sec, 2-m (6.6-ft) waves (prototype)

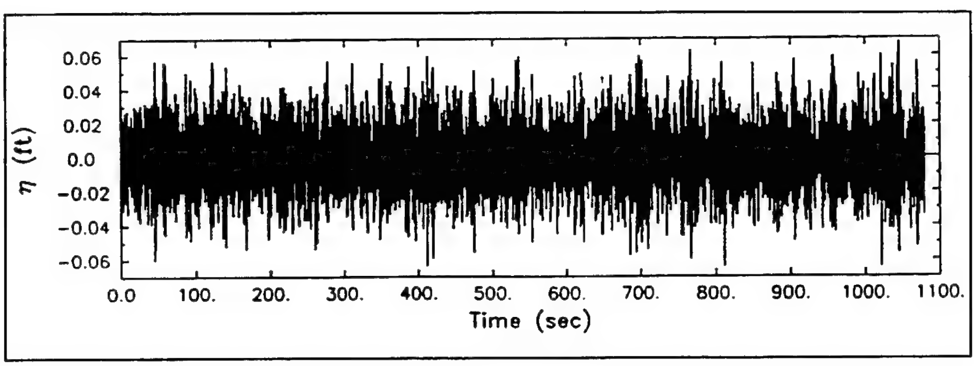

Figure 8. Typical model-scale wave train time series; 12-sec, 2-m (6.6-ft) wave (prototype)

Analysis of Model Data

Relative merits of the various plans were evaluated by:

a. Comparison of wave heights at selected locations in the model.

b. Comparison of wave-induced current patterns and magnitudes.

c. Comparison of sediment tracer movement and subsequent deposits.

d. Visual observations and wave pattern photographs.

In the wave-height data analysis, the average height of the highest one-third of the waves (H_s), recorded at each gauge location, was computed. All wave heights then were adjusted by application of Keulegan's equation[1] to compensate for excessive model wave height attenuation due to viscous bottom friction. From this equation, reduction of model wave heights (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel, and the model data can be corrected and converted to their prototype equivalents.

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[1]G. H. Keulegan. (1950). "The Gradual Damping of a Progressive Oscillatory Wave with Distance in a Prismatic Rectangular Channel," Unpublished data, National Bureau of Standards, Washington, DC, prepared at request of Director, WES, Vicksburg, MS, by letter of 2 May 1950.

4 Experiments and Results

Experiments

Existing conditions

Comprehensive wave height experiments were conducted for existing conditions (Plate 1) to establish a base from which to evaluate the effectiveness of the various improvement plans. Wave height data were secured at various locations in the existing and proposed harbor areas. In addition, wave-induced current patterns and magnitudes and sediment tracer experiments were conducted for representative wave conditions.

Improvement plans

Preliminary experiments of proposed improvement plans were initially conducted. These experiments consisted of expeditiously constructed breakwaters, causeway extensions, and/or channel alignments. Breakwaters were constructed with concrete blocks in some cases, and with stone in other instances. The stone breakwaters and causeway extensions consisted of an impermeable core (el +0.9 m (+3.0 ft)) with 7,257-kg (8-ton) armor stone constructed to a crest elevation of +4.0 m (+13.0 ft) on approximate 1V:1.5H side slopes. Deepening of the entrance channels and the turning and deposition basins was accomplished by removing the existing bottom contours and molding pea gravel to the required depths. Wave heights were obtained for most preliminary plans and wave-induced current patterns and magnitudes as well as tracer patterns and subsequent deposits were observed. These experiments were conducted in an expeditious manner only to determine how relative changes would affect hydrodynamic conditions. Results were viewed in a relative sense only due to the nature of the construction. Brief descriptions of preliminary improvement plans are presented in the following subparagraphs; dimensional details are shown in Plates 2-9.

a. Plan 1 (Plate 2) consisted of the installation of a 808-m-long (2,650-ft-long) block breakwater. The structure originated approximately 463 m (1,520 ft) east of the existing causeway and extended seaward parallel to the causeway 408 m (1,340 ft) before doglegging to the southwest. The navigation opening between the new breakwater and the causeway was 213 m (700 ft) wide.

b. Plan 2 (Plate 2) included the elements of Plan 1 with a 198-m-long (650-ft-long) seaward extension of the breakwater, resulting in a 1,006-m-long (3,300-ft-long) structure.

c. Plan 3 (Plate 2) entailed the elements of Plan 1 but the dogleg portion of the breakwater was reoriented slightly to the west and extended by 46 m (150 ft) in length. This resulted in an 853-m-long (2,800-ft-long) structure with a 122-m-wide (400-ft-wide) navigation opening between the breakwater and the causeway dock.

d. Plan 4 (Plate 3) consisted of the elements of Plan 2 with a slight reorientation of, and a 12.2-m-long (40-ft-long) extension to, the block dogleg breakwater. This resulted in a 1,018-m-long (3,340-ft-long) structure. A 107-m-wide (350-ft-wide), 6.7-m-deep (22-ft-deep) entrance channel, and a 6.7-m-deep (22-ft-deep) turning area (adjacent to the docks on the causeway) were installed. From this point the channel transitioned to 45.7 m (150 ft) in width and 3.7 m (12 ft) in depth and extended northerly through the sand spit into the Snake River and then easterly into the existing harbor. A 3.7-m-deep (12-ft-deep) deposition basin also was installed between the 3.7-m-deep (12-ft-deep) inner channel and the causeway.

e. Plan 5 (Plate 3) involved the elements of Plan 4, but the breakwater was reduced in length by 110 m (360 ft) and the outer end was reoriented to the west. The total breakwater length was 908 m (2,980 ft) and the navigation opening was 137 m (450 ft) in width between the breakwater and the causeway dock. The existing harbor entrance also was closed.

f. Plan 6 (Plate 4) entailed the elements of Plan 5 with a 41.1-m-long (135-ft-long) southerly extension of the causeway. The causeway extension was of rubble-mound construction.

g. Plan 7 (Plate 4) included the elements of Plan 6 with an additional 15.2-m (50-ft) extension of the causeway, resulting in a 56.4-m-long (185-ft-long) structure.

h. Plan 8 (Plate 4) involved the elements of Plan 7, but the breakwater was reduced by 73 m (240 ft) in length and its head reoriented westerly. The total structure length was 835 m (2,740 ft), and the 137-m-wide (450-ft-wide) navigation opening was maintained between the breakwater and the causeway dock.

i. Plan 9 (Plate 5) consisted of the installation of a 927-m-long (3,040-ft-long) rubble-mound breakwater. The structure originated approximately 579 m (1,900 ft) east of the causeway and extended seaward parallel to the entrance channels before it curved to the southwest. The navigation opening between the breakwater and the outer causeway dock was 137 m (450 ft) in width. The plan also included the dredging described in Plan 4, and the existing harbor entrance was closed.

j. Plan 10 (Plate 5) entailed the elements of Plan 9 with a 56.4-m (185-ft) rubble causeway extension to the south. The distance between the toes of the breakwater and the causeway extension was 119 m (390 ft).

k. Plan 11 (Plate 5) involved the elements of Plan 10 with an additional 15.2-m (50-ft) causeway extension, resulting in a 71.6-m-long (235-ft-long) structure. The distance between the toes of the breakwater and causeway extension was 115.8 m (380 ft).

l. Plan 12 (Plate 5) consisted of the elements of Plan 9, but the breakwater was decreased by 61 m (200 ft) in length and its head was reoriented to the west. This resulted in an 866-m-long (2,840-ft-long) structure with a 137-m (450-ft) width between the toe of the breakwater and the outer causeway dock face.

m. Plan 13 (Plate 6) included the elements of Plan 9, but a 9.1-m-wide (30-ft-wide) breach was installed in the breakwater approximately 167.6 m (550 ft) seaward of the shoreline.

n. Plan 14 (Plate 6) involved the elements of Plan 13 with a 71.6-m-long (235-ft-long) causeway extension. The navigation opening was 115.8 m (380 ft) in width between the toes of the breakwater and the causeway extension.

o. Plan 15 (Plate 6) entailed the elements of Plan 14 but the causeway extension was reduced in length by 15.2 m (50 ft) resulting in a 56.4-m-long (185-ft-long) structure with a 119-m (390-ft) navigation opening measured between the toes of the breakwater and the causeway extension.

p. Plan 16 (Plate 7) consisted of the elements of Plan 14 but an area southwest of the head of the causeway was raised with gravel to represent shoaling that may be expected over the next 10 years. These contours were raised 0.9 m (3 ft) in elevation.

q. Plan 17 (Plate 8) entailed the dredging elements of Plan 4 with no breakwater in place. The entrance to the existing harbor, however, was closed.

r. Plan 18 (Plate 9) involved the elements of Plan 17 but the stone revetment along the existing breach in the causeway was removed to slightly increase its width and the depths were increased from about 1.1 to 2.4 m (3.5 to 8 ft). The plan also included the installation of a dredged deposition basin eastward of the breach. The basin paralleled the shoreline and causeway and extended southeasterly in an arc about 122 m (400 ft) in diameter. It was 6.7 m (22 ft) deep.

The final improvement plan (Plan 19) was developed as a result of the preliminary experiments. Plan 19 (Plate 10) consisted of a 107-m-wide (350-ft-wide), 6.7-m-deep (22-ft-deep) entrance channel and a 6.7-m-deep (22-ft-deep) turning area (adjacent to the docks on the causeway). From this point the channel transitioned to 45.7 m (150 ft) in width and 3.7 m (12 ft) in depth and extended approximately 274 m (900 ft) where it again transitioned to 3 m (10 ft) in depth before extending to the north through the sand spit into Snake River and then easterly to the existing harbor. The breach in the existing causeway was widened to 18.3 m (60 ft) with a depth of 2.4 m (8 ft), and a 6.7-m-deep (22-ft-deep) deposition basin was included eastward of the breach. The plan also entailed a 71.6-m-long (235-ft-long) rubble spur breakwater extending to the south from the causeway. The spur had an 8.8-m-wide (29-ft-wide) crest with an elevation of +4.3 m (+14 ft) and was armored with 19,958-kg (22-ton) stone on 1V:1.5H side slopes. Underlayer stone ranged from 1,361 to 2,495 kg (3,000 to 5,500 lb) and core stone ranged from 0.45 to 295 kg (1 to 650 lb). Thicknesses of the underlayer and armor layer stone were 2.1 and 4.6 m (7 and 15 ft), respectively. Also in-cluded in the plan was a new 909.8-m-long (2,985-ft-long) rubble-mound breakwater. The breakwater originated approximately 579 m (1,900 ft) east of the causeway and extended seaward 457 m (1,500 ft) parallel to the entrance channels before turning slightly southwesterly. The breakwater had a 3.7-m-wide (12-ft-wide) crest with an elevation of +4.3 m (+14 ft) and was armored with 7,257-kg (8-ton) stone on 1V:1.5H side slopes. Underlayer stone ranged from 363 to 907 kg (800 to 2,000 lb) and core stone ranged from 0.45 to 295 kg (1 to 650 lb). Thicknesses of the underlayer and armor layer stone were 1.5 and 3 m (5 and 10 ft), respectively. The new breakwater included a 9.1-m-wide (30-ft-wide) breach approximately 244 m (800 ft) seaward of its origination point. The navigation opening between the new breakwater toe and the causeway extension toe was 115.8 m (380 ft) wide. The existing entrance to the small-boat harbor also was closed for this plan.

Wave height experiments

Wave height experiments were conducted for existing conditions and various improvement plans for representative experimental waves from the various incident directions. Experiments involving some proposed plans were limited to the most critical direction of wave approach. Wave gauge locations are shown in referenced plates.

Wave-induced current patterns and magnitudes

Wave-induced current patterns and magnitudes were obtained for existing conditions and selected improvement plans for representative experimental waves from the various incident directions. These experiments were conducted by timing the progress of a dye tracer relative to a known distance on the model surface at selected locations in the model.

Sediment tracer experiments

Sediment tracer experiments were conducted for existing conditions and selected plans of improvement for representative experimental waves from the various incident directions. Sediment tracer was introduced into the model along the shoreline, or along the causeway and/or proposed breakwater to define sediment tracer patterns and subsequent deposition areas.

Experimental Results

In analyzing results, the relative merits of various improvement plans were based on measured wave heights, wave-induced current patterns and magnitudes, and the movement of sediment tracer material and deposition areas. Model wave heights (significant wave heights or H_s) were tabulated to show measured values at selected locations. Wave-induced current patterns and magnitudes, and sediment tracer patterns and subsequent deposition areas were shown on plates.

Existing conditions

Results of wave height experiments for existing conditions are presented in Table 1. For the +0.5-m (+1.6-ft) swl, maximum wave heights[1] were as follows:

Outer causeway dock (gauge 5) 12-sec, 3-m (9.8-ft) waves from 137 deg	4.66 m (15.3 ft)
Inner causeway dock (gauge 6) 12-sec, 3-m (9.8-ft) waves from 137 deg	3.2 m (10.5 ft)
Existing entrance (gauge 12) 12- and 24-sec, 3-m (9.8-ft) waves from 182 deg	1.65 m (5.4 ft)
Existing channel (gauge 11) 24-sec, 3-m (9.8-ft) waves from 182 deg	0.98 m (3.2 ft)
Existing turning basin (gauge 10) 2- and 3-m (6.6- and 9.8-ft) waves from 182, 212, and 227 deg	0.37 m (1.2 ft)

For the +4.0-m (+13.0-ft)swl, maximum wave heights were as follows:

[1]Refers to maximum significant wave heights throughout report.

Outer causeway dock 12-sec, 6-m (19.7-ft) waves from 137 deg	6.98 m (22.9 ft)
Inner causeway dock 12-sec, 6-m (19.7-ft) waves from 137 deg	5.63 m (18.5 ft)
Existing entrance 12-sec, 3-m (9.8-ft) waves from 257 deg	3.7 m (12.0 ft)
Existing channel 12-sec, 6-m (19.7-ft) waves from 137 deg	1.4 m (4.6 ft)
Existing turning basin 12-sec, 6-m (19.7-ft) waves from 137 deg	0.49 m (1.6 ft)

Current patterns and magnitudes obtained for existing conditions are presented in Plates 11-21 for representative wave conditions and directions. For waves from 257, 227, and 212 deg, currents generally moved easterly along the shoreline, southerly around the head of the causeway, and then easterly again. However, currents in the lee (east) of the causeway moved southerly adjacent to the structure and then in a counterclockwise eddy. For waves from 182 and 137 deg, currents generally moved westerly along the shoreline, southerly around the head of the causeway, and then westerly again. Currents in the lee (west) of the causeway moved southerly adjacent to the structure and then in a clockwise eddy. Maximum velocities, for the experiments conducted, occurred for 12-sec, 6-m (19.7-ft) waves from 257 deg with the +4.0-m (+13.0-ft) swl. Maximum velocities of 2.2 mps (7.1 fps) were obtained around the head of the causeway for these extreme wave and water level conditions. Maximum velocities identified for the +0.5-m (+1.6-ft) swl were 0.8 mps (2.6 fps) adjacent to the west side of the causeway for 9-sec, 2-m (6.6-ft) waves from 212 deg; 1 mps (3.3 fps) adjacent to the outer dock on the east side of the causeway for 12-sec, 2-m (6.6-ft) waves from 137 deg; and 0.5 mps (1.8 fps) along the shoreline between the causeway and the existing entrance for 9-sec, 2-m (6.6-ft) waves from 182 deg.

The general movement of tracer material for representative waves from 212, 182, and 137 deg is shown in Plates 22-24 for existing conditions. Sediment initially tended to move toward the shoreline and then, in general, moved easterly for waves from 212 deg and westerly for waves from 182 and 137 deg. Tracer material moved easterly through the breach in the causeway for waves from 212 deg and westerly through the breach for waves from 137 deg.

Improvement plans

Results of wave height experiments for Plans 1-12 are presented in Table 2 for representative waves for the +0.5-m (+1.6-ft) swl from various directions. For Plans 1-3, for experimental waves from 137 deg, maximum wave heights obtained without a dredged entrance channel were as follows:

Outer causeway dock (gauge 5) Plan 1	2.47 m (8.1 ft)
Outer causeway dock (gauge 5) Plan 2	1.31 m (4.3 ft)
Outer causeway dock (gauge 5) Plan 3	2.74 m (9.0 ft)
Inner causeway dock (gauge 6) Plan 1	2.01 m (6.6 ft)
Inner causeway dock (gauge 6) Plan 2	0.46 m (1.5 ft)
Inner causeway dock (gauge 6) Plan 3	0.79 m (2.6 ft)

After dredging of the proposed channels, maximum wave heights for Plans 4-6 for experimental waves from 137 deg were as follows:

Outer causeway dock Plan 4	0.7 m (2.3 ft)
Outer causeway dock Plan 5	2.41 m (7.9 ft)
Outer causeway dock Plan 6	2.32 m (7.6 ft)
Inner causeway dock Plan 4	0.24 m (0.8 ft)
Inner causeway dock Plan 5	0.64 m (2.1 ft)
Inner causeway dock Plan 6	0.61 m (2.0 ft)
Turning area (gauge 13) Plan 4	0.4 m (1.3 ft)
Turning area (gauge 13) Plan 5	0.64 m (2.1 ft)
Turning area (gauge 13) Plan 6	0.64 m (2.1 ft)
Interior channel (gauge 8) Plan 4	0.09 m (0.3 ft)
Interior channel (gauge 8) Plan 5	0.06 m (0.2 ft)
Interior channel (gauge 8) Plan 6	0.06 m (0.2 ft)

For Plans 5-11, for experimental waves from 227 deg in the interior channel, maximum wave heights were as follows:

Outer causeway dock Plan 5	1.98 m (6.5 ft)
Outer causeway dock Plan 6	1.43 m (4.7 ft)
Outer causeway dock Plan 7	1.28 m (4.2 ft)
Outer causeway dock Plan 8	1.34 m (4.4 ft)
Outer causeway dock Plan 9	2.01 m (6.6 ft)
Outer causeway dock Plan 10	1.25 m (4.1 ft)
Outer causeway dock Plan 11	1.01 m (3.3 ft)
Inner causeway dock Plan 5	0.82 m (2.7 m)
Inner causeway dock Plan 6	0.7 m (2.3 ft)
Inner causeway dock Plan 7	0.7 m (2.3 ft)
Inner causeway dock Plan 8	0.76 m (2.5 ft)
Inner causeway dock Plan 9	0.76 m (2.5 m)
Inner causeway dock Plan 10	0.64 m (2.1 ft)
Inner causeway dock Plan 11	0.58 m (1.9 ft)
Turning area Plan 5	1.49 m (4.9 ft)
Turning area Plan 6	1.28 m (4.2 ft)
Turning area Plan 7	1.25 m (4.1 ft)
Turning area Plan 8	1.43 m (4.7 ft)
Turning area Plan 9	1.52 m (5.0 ft)
Turning area Plan 10	1.28 m (4.2 ft)
Turning area Plan 11	1.1 m (3.6 ft)

Interior channel Plan 5	0.15 m (0.5 ft)
Interior channel Plan 6	0.12 m (0.4 ft)
Interior channel Plan 7	0.15 m (0.5 ft)
Interior channel Plan 8	0.12 m (0.4 ft)
Interior channel Plan 9	0.15 m (0.5 ft)
Interior channel Plan 10	0.12 m (0.4 ft)
Interior channel Plan 11	0.09 m (0.3 ft)

Maximum wave heights for Plans 9 and 11 for 182-deg waves were as follows:

Outer causeway dock Plan 9	2.47 m (8.1 ft)
Outer causeway dock Plan 11	1.74 m (5.7 ft)
Inner causeway dock Plan 9	1.22 m (4.0 ft)
Inner causeway dock Plan 11	1.07 m (3.5 ft)
Turning area Plan 9	1.37 (4.5 ft)
Turning area Plan 11	1.37 m (4.5 ft)
Interior channel Plan 9	0.12 m (0.4 ft)
Interior channel Plan 11	0.12 m (0.4 ft)

Maximum wave heights for Plans 9 and 12 for waves from 137 deg were as follows:

Outer causeway dock Plan 9	2.41 m (7.9 ft)
Outer causeway dock Plan 12	2.56 m (8.4 ft)
Inner causeway dock Plan 9	0.7 m (2.3 ft)
Inner causeway dock Plan 12	0.94 m (3.1 ft)
Turning area Plan 9	0.46 m (1.5 ft)
Turning area Plan 12	0.58 m (1.9 ft)
Interior channel Plan 9	0.06 m (0.2 ft)
Interior channel Plan 12	0.06 m (0.2 ft)

Wave heights obtained for Plans 13-16 are presented in Table 3 for various directions and/or swl's. For 12-sec, 5-m (16.4-ft) waves from 137 deg with the +0.5-m (+1.6-ft) swl, maximum wave heights were as follows:

Outer causeway dock (gauge 5) Plan 13	4.82 m (15.8 ft)
Outer causeway dock (gauge 5) Plan 14	4.48 m (14.7 ft)
Inner causeway dock (gauge 6) Plan 13	1.43 m (4.7 ft)
Inner cause dock (gauge 6) Plan 14	1.37 m (4.5 ft)
Turning area (gauge 13) Plan 13	1.4 m (4.6 ft)
Turning area (gauge 13) Plan 14	1.31 m (4.3 ft)
Interior channel (gauge 8) Plan 13	0.27 m (0.9 ft)
Interior channel (gauge 8) Plan 14	0.3 m (1.0 ft)

For 9-sec waves from 227 deg with the +0.5-m (+1.6-ft) swl, maximum wave heights for Plans 14 and 15 were as follows:

Outer causeway dock Plan 14	0.64 m (2.1 ft)
Outer causeway dock Plan 15	0.73 m (2.4 ft)
Inner causeway dock Plan 14	0.3 m (1.0 ft)
Inner causeway dock Plan 15	0.34 m (1.1 ft)
Turning area Plan 14	0.85 m (2.8 ft)
Turning area Plan 15	0.98 m (3.2 ft)
Interior channel Plan 14	0.06 m (0.2 ft)
Interior channel Plan 15	0.06 m (0.2 ft)

For Plan 14, 12-sec, 5-m (15.4-ft) waves from 227 deg with the +0.5-m (+1.6-ft) swl resulted in the following maximum wave heights:

Outer causeway dock	2.0 m (6.7 ft)
Inner causeway dock	1.43 m (4.7 ft)
Turning area	2.13 m (7.0 ft)
Interior channel	0.27 m (0.9 ft)

Maximum wave heights for Plan 16 from the 227-deg direction for 12-sec, 2-m (6.6-ft) waves with the +0.5-m (+1.6-ft) swl were as follows:

Outer causeway dock	0.94 m (3.1 ft)
Inner causeway dock	0.49 m (1.6 ft)
Turning area`	0.94 m (3.1 ft)
Interior channel	0.09 m (0.3 ft)

For the 182-deg direction with the +0.5-m (+1.6-ft) swl and 12-sec, 5-m (16.4-ft) wave conditions, maximum wave heights for Plan 14 were as follows:

Outer causeway dock	4.48 m (14.7 ft)
Inner causeway dock	1.77 m (5.8 ft)
Turning area	2.13 m (7.0 ft)
Interior channel	0.3 m (1.0 ft)

Maximum wave heights for Plan 14 for 12-sec, 6-m (19.7-ft) waves from the 182-deg direction were as follows:

Outer causeway dock	6.71 m (22.0 ft)
Inner causeway dock	3.35 m (11.3 ft)
Turning area	3.11 m (10.2 ft)
Interior channel	0.73 m (2.4 ft)

For 12-sec, 6-m (19.7-ft) waves from 227 deg, maximum wave heights for Plans 14 and 16 were as follows:

Outer causeway dock Plan 14	2.96 m (9.7 ft)
Outer causeway dock Plan 16	2.96 m (9.7 ft)
Inner causeway dock Plan 14	1.83 m (6.0 ft)
Inner causeway dock Plan 16	1.77 m (5.8 ft)
Turning area Plan 14	2.65 m (8.7 ft)
Turning area Plan 16	2.74 m (9.0 ft)
Interior channel Plan 14	0.46 m (1.5 ft)
Interior channel Plan 16	0.52 m (1.7 ft)

Current patterns and magnitudes obtained for Plans 13-15 are presented in Plates 25-41 for various wave conditions and incident directions. For waves from 137 deg with Plan 13 installed, currents east of the new breakwater moved westerly along the shoreline and then southerly along the new structure. Currents west of the causeway also moved seaward along the structure. Maximum velocities were 1.52 mps (5.0 fps) adjacent to the new breakwater and 0.98 mps (3.2 fps) adjacent to the causeway for 5-m (16.4-ft) wave conditions with the +0.5-m (+1.6-ft) swl. For Plan 14 with waves from 182 deg, currents along the shoreline east of the new breakwater and west of the existing entrance moved to the west along the shoreline and then to the south along the new structure. Currents east of the existing entrance moved in an easterly direction. Currents west of the causeway moved seaward along the structure. Maximum velocities were 1.65 mps (5.4 fps) along the new breakwater for 12-sec, 5-m (16.4-ft) waves and 0.55 mps (1.8 fps) along the causeway for 12-sec, 2- and 5-m (6.6- and 16.4-ft) waves. Currents along the shoreline east of the new breakwater, with Plans 14 and 15 installed, split for waves from 227 deg. Some moved easterly toward the existing entrance and along the shoreline, while some moved westerly along the shoreline and then southerly along the new structure. Currents west of the causeway moved seaward along the structure for both plans. Maximum velocities were 1.13 mps (3.7 fps) along the new breakwater and 1.43 mps (4.7 fps) along the causeway for Plan 14 for 12-sec,

5-m (16.4-ft) wave conditions with the +1.5-ft (+1.6-ft) swl. Maximum velocities seaward of the new entrance (along the causeway extension) for Plan 14 were 1.62 mps (5.3 fps) for 12-sec, 6-m (19.7-ft) waves with the +4.0-m (+13.0-ft) swl.

The general movement of tracer material for representative waves from 137, 182, and 227 deg is presented in Plates 42-47 for Plans 13 and/or 14. For waves from 137 deg, sediment along the shoreline west of the causeway moved to the east toward the structure, and sediment along the causeway moved seaward for Plans 13 and 14. Sediment along the shoreline east of the new breakwater moved shoreward and slightly to the west, sediment midway along the new breakwater split, with some moving to the north and some to the south, and sediment along the seaward portion of the new structure moved seaward along the breakwater. For waves from 182 deg with Plan 14 installed, sediment along the shoreline west of the causeway moved to the east toward the structure, and sediment along the causeway split with some moving shoreward and some seaward along the structure. Sediment along the shoreline east of the new breakwater moved shoreward and slightly west, while sediment along the midway portion of the new breakwater moved to the north along the structure and through the breach, and sediment along the head of the new breakwater moved seaward and across the new entrance. For waves from 227 deg with Plan 14 installed, sediment along the shoreline west of the causeway moved east toward the structure, and sediment along the causeway moved seaward along the structure around its head and across the entrance. Sediment along the shoreline east of the new breakwater generally migrated shoreward; sediment about midway along the new breakwater moved to the north; and sediment in the vicinity of the head of the new breakwater moved seaward.

Results of wave height experiments for Plan 17 are presented in Table 4 for 9- and 12-sec waves from 227, 182, and 137 deg with the +0.5-m (+1.6-ft) swl. For 2-m (6.6-ft) wave conditions, maximum wave heights were as follows:

Outer causeway dock (gauge 5) Waves from 137 deg	2.71 m (8.9 ft)
Inner causeway dock (gauge 6) Waves from 137 deg	2.56 m (8.4 ft)
Turning area (gauge 13) Waves from 182 deg	2.62 m (8.6 ft)
Interior channel (gauge 8) Waves from 137 deg	0.3 m (1.0 ft)

For 5-m (16.4-ft) incident conditions, maximum wave heights were as follows:

Outer causeway dock Waves from 137 deg	5.61 m (18.4 ft)
Inner causeway dock Waves from 137 deg	4.02 m (13.2 ft)
Turning area Waves from 182 deg	3.41 m (11.2 ft)
Interior channel Waves from 137 deg	0.4 m (1.3 ft)
Interior channel Waves from 182 deg	0.4 m (1.3 ft)

Current patterns and magnitudes obtained for Plan 17 are presented in Plates 48-62 for various waves from 137, 182, and 227 deg. For waves from 137 and 182 deg, currents along the shoreline east of the causeway generally moved westerly, seaward along the structure, and then westerly around the head of the causeway. Currents west of the causeway moved seaward along the structure. For waves from 227 deg, currents along the shoreline east of the causeway moved easterly and currents adjacent to the east side of the structure moved seaward. Currents west of the causeway also moved seaward along the structure. Maximum velocities were 1.07 mps (3.5 fps) adjacent to the west side of the causeway for 12-sec, 5-m (16.4-ft) waves from 137 deg; 0.91 and 2.04 mps (3.0 and 6.7 fps) along the inner and outer causeway docks, respectively, for 12-sec, 5-m (16.4-ft) waves from 227 deg; and 0.85 mps (2.8 fps) along the shoreline between the causeway and the existing entrance for 12-sec, 5-m (16.4-ft) waves from 137 and 182 deg.

The general movement of tracer material for representative waves from 137, 182, and 227 deg is shown in Plates 63-65 for Plan 17. Sediment along the shoreline east of the causeway between the proposed and existing entrances generally moved shoreward and then easterly for waves from 227 deg and westerly for waves from 182 and 137 deg. Sediment along the shoreline west of the causeway moved to the east through the breach for waves from 227 deg. This material split and moved in both directions (east and west) for waves from 182 and 137 deg. Sediment along the west side of the causeway at its outer end moved around the head of the causeway for waves from 227 deg, but for waves from 182 and 137 deg, moved in a clockwise eddy at the outer end of the structure.

Tracer material was placed west of the causeway along the shoreline for Plan 18 and subjected to representative waves from 227 deg. Visual observations revealed that material would move to the east through the breach in the causeway and deposit in a clockwise eddy in the deposition basin.

Results of wave height experiments for Plan 19 are presented in Table 5 for representative waves from 227, 182, and 137 deg. For 2-m (6.6-ft) wave conditions with the +0.5-m (+1.6-ft) swl, maximum wave heights were as follows:

Outer causeway dock (gauge 5) Waves from 137 deg	2.56 m (8.4 ft)
Inner causeway dock (gauge 6) Waves from 182 deg	1.1 m (3.6 ft)
Turning area (gauge 13) Waves from 182 deg	1.25 m (4.1 ft)
Interior channel (gauge 8) Waves from 182 deg	0.15 m (0.5 ft)
Interior channel (gauge 8) Waves from 137 deg	0.15 m (0.5 ft)

For the +0.5-m (+1.6-ft) swl with 5-m (16.4-ft) incident waves, maximum wave heights were as follows:

Outer causeway dock Waves from 137 deg	4.69 m (15.4 ft)
Inner causeway dock Waves from 182 deg	1.77 m (5.8 ft)
Turning area Waves from 182 deg	2.16 m (7.1 ft)
Interior channel Waves from 182 deg	0.34 m (1.1 ft)

Maximum wave heights for 6-m (19.7-ft) waves with the +4.0-m (+13.0-ft) swl were as follows:

Outer causeway dock Waves from 182 deg	5.97 m (19.6 ft)
Inner causeway dock Waves from 137 deg	3.99 m (13.1 ft)
Turning area Waves from 137 deg	3.11 m (10.2 ft)
Interior channel Waves from 182 deg	0.85 m (2.8 ft)

Typical wave patterns for representative waves from 227, 182, and 137 deg are shown in Photos 1-9 for Plan 19.

Current patterns and magnitudes obtained for Plan 19 are presented in Plates 66-80 for representative waves from 227, 182, and 137 deg. For waves from all wave directions, currents along the shoreline between the new breakwater and the existing entrance moved to the west, and then seaward adjacent to the east side of the structure; and currents west of the causeway moved seaward along the structure. For waves from 227 and 182 deg, currents east of the existing entrance moved in an easterly direction, while they moved to the west for waves from 137 deg. Currents entered the harbor through the breach in the causeway for waves from 227 and

182 deg, and through the breach in the new breakwater for waves from 182 and 137 deg. Maximum velocities were 1.34 mps (4.4 fps) adjacent to the west side of the causeway; 1.86 mps (6.1 fps) through the breach in the causeway; 0.46 and 0.61 mps (1.5 and 2.0 fps) along the inner and outer causeway docks, respectively; and 0.40 mps (1.3 fps) in the new entrance channel for 12-sec, 5-m (16.4-ft) waves from 227 deg; and 2.13 mps (7.0 fps) adjacent to the east side of the new breakwater; 2.26 mps (7.4 fps) through the breach in the new breakwater; and 0.79 mps (2.6 fps) along the shoreline between the new breakwater and the existing entrance for 12-sec, 5-m (16.4-ft) waves from 137 deg.

The general movement of tracer material for 5- and 6-m (16.4- and 19.7-ft) waves from 227, 182, and 137 deg is shown in Plates 81-86 for Plan 19. For waves from 227 deg, sediment along the shoreline west of the causeway moved east toward the structure. The extreme wave conditions (12-sec, 6-m (19.7-ft) waves) resulted in material moving through the breach in the causeway and depositing in the deposition basin. For waves from 182 and 137 deg, this material tended to split, with some moving westerly and some moving easterly toward the causeway. Sediment did not move through the breach in the causeway for these directions. Tracer material adjacent to and west of the causeway moved seaward and around the head of the structure for waves from 227 deg; but for waves from 182 and 137 deg, tracer tended to split with some migrating seaward along the causeway and some moving northerly along the structure. Sediment along the shoreline east of the new breakwater and west of the existing entrance generally moved shoreward and then westerly for waves from all three directions, though a slight amount of easterly movement was noted for some conditions. In addition, sediment adjacent to and east of the new breakwater about midway generally moved northerly for waves from 227 and 182 deg and seaward for waves from 137 deg, while sediment in the vicinity of the head of the new structure moved seaward for waves from all three directions, with a slight amount moving northerly for waves from 227 and 182 deg.

Discussion of experimental results

Results of wave height experiments for existing conditions indicated rough and turbulent wave conditions in the existing entrance as well as along the existing causeway docks. Wave heights in the entrance exceeded 1.5 m (5 ft) for typical storm wave conditions (2-m (6.6-ft) waves). In addition, very confused and turbulent wave patterns were observed in the entrance due to reflected wave energy off the vertical walls. Wave heights along the existing outer and inner causeway docks were in excess of 3.7 and 2.7 m (12 and 9 ft), respectively, for typical storm wave conditions. For 50-year storm conditions (6-m (19.7-ft) waves), wave heights obtained in the entrance were almost 3.7 m (12 ft) in height and wave heights along the outer and inner docks were almost 7.0 and 5.8 m (23 and 19 ft), respectively.

Preliminary experiments conducted with expeditiously constructed improvement plans (Plans 1-15) proved very beneficial in providing model data in an efficient manner. The lengths and alignments of the new breakwater and causeway extension were preliminarily determined relative to wave heights obtained in the harbor. These improvement plans also indicated the impacts of the structures on wave-

induced current patterns and magnitudes and sediment tracer movement and subsequent deposits. Experimental results obtained from these preliminary plans were used as a basis for determining the optimum improvement plan (Plan 19).

Wave height experiments conducted for Plan 16 indicated that the raised bathymetry southwest of the head of the causeway (representing shoaling over a 10-year period) slightly reduced wave heights in the harbor relative to the existing depths of Plan 14. Since the area was raised expeditiously with gravel, however, the additional bottom friction may have contributed to the reduced heights as opposed to the bathymetry change. These results are, therefore, considered nonconclusive.

Preliminary experiments with the dredged areas only (breakwater and causeway extension removed) of Plan 17 revealed increases in wave heights at the causeway docks. For 2-m (6.6-ft) wave conditions, maximum wave heights at the outer and inner docks increased by 0.52 and 1.49 m (1.7 and 4.9 ft), respectively, due to removal of the breakwater and causeway extension. Preliminary results also revealed current magnitudes in excess of 0.61 mps (2.0 fps) along the outer causeway dock and in the entrance channel for 2-m (6.6-ft) wave conditions for Plan 17. In addition, the removal of the breakwater would increase the potential for channel shoaling.

During preliminary experiments, visual observations revealed that the 3.7-m-deep (12-ft-deep) deposition basin was not very effective in catching and storing sediment for waves predominantly from the southwest. The slight deepening and widening of the breach in conjunction with the 6.7-m-deep (22-ft-deep) deposition (Plan 18) increased the effectiveness of the sand management system and was used as a basis for the final design plan.

Results of wave height experiments for the final (optimum) improvement plan (Plan 19) revealed calm conditions (wave heights of 0.15 m (0.5 ft) or less) in the existing harbor (gauge 9) during typical storm wave conditions (2-m (6.6-ft) waves). For 50-year storm wave conditions (6-m (19.7-ft) waves), wave heights of 0.52 m (1.7 ft) or less occurred in the harbor. Wave heights obtained along the outer and inner causeway docks were 1.16 and 0.61 m (3.8 and 2.0 ft), respectively, for predominant 2-m (6.6-ft) waves from 227 deg. For 50-year storm conditions, wave heights along the outer and inner docks were 6.0 and 4.0 m (19.6 and 13.1 ft), respectively. Results indicated that wave heights for Plan 19 were substantially less than those obtained for existing conditions.

Wave-induced current patterns obtained for Plan 19, in general, indicated current movement from west to east for waves from 227 deg with a counterclockwise eddy east of the new breakwater. This eddy resulted in currents moving seaward along the new breakwater. For waves from 182 and 137 deg, current movement was generally from east to west with a clockwise eddy west of the existing causeway, even though in some cases, movement east of the existing entrance was in an easterly direction. Current patterns and magnitudes were similar to existing conditions, except that currents moved along the eastern side of the new breakwater as opposed to the eastern side of the existing causeway. The breaches in the causeway and breakwater provided some circulation between the structures.

Sediment tracer movement for Plan 19 also was similar to that obtained for existing conditions, but sediment moved east of the new breakwater as opposed to east of the existing causeway. The new breakwater configuration should have minimal impacts on current and sediment movement patterns in the immediate vicinity.

The widened and deepened breach in the existing causeway and the 6.7-m-deep (22-ft-deep) deposition basin of Plan 19 was very effective in trapping sediment for waves from the predominate 227-deg direction, particularly for storm waves with the higher swl's. Sediment moved through the breach and deposited in a clockwise eddy in the deposition basin.

5 Conclusions

Based on results of the coastal model investigation reported herein, it is concluded that:

a. Existing conditions are characterized by rough and turbulent wave conditions in the existing entrance. Very confused wave patterns were observed in the entrance due to reflected wave energy off the vertical walls lining the entrance. Wave heights in excess of 1.5 m (5 ft) were obtained in the entrance for typical storm conditions; and wave heights of almost 3.7 m (12 ft) were obtained in the entrance for 50-year storm wave conditions with extreme high water levels (+4 m (+13 ft)).

b. Wave conditions along the vertical-faced causeway docks were excessive for existing conditions. Wave heights in excess of 3.7 and 2.7 m (12 and 9 ft) were obtained along the outer and inner docks, respectively, for typical storm conditions; and wave heights of almost 7.0 and 5.8 m (23 and 19 ft) were recorded along these docks, respectively, for 50-year storm wave conditions with extreme highwater levels.

c. Preliminary experiments provided an excellent means to expeditiously evaluate various improvement plans (Plans 1-18) with respect to wave heights, wave-induced current patterns and magnitudes, and sediment tracer patterns and subsequent deposits. These experimental results were used as a basis for development of the final improvement plan (Plan 19).

d. The final improvement plan (Plan 19) will result in calm conditions (wave heights of 0.15 m (0.5 ft) or less) in the existing harbor during typical storm conditions. For 50-year storm conditions with extreme highwater levels, wave heights will not exceed 0.52 m (1.7 ft) in the harbor.

e. Wave heights at the causeway docks, particularly the inner dock, will be significantly reduced as a result of the Plan 19 breakwater configuration during both typical and extreme (50-year) storm wave events.

f. The Plan 19 breakwater configuration will have no adverse impacts on current patterns and magnitudes and/or the movement of sediment in the immediate area.

g. The widened and deepened breach in the existing causeway, in conjunction with the deposition basin of Plan 19, will be effective in trapping sediment (particularly for storm waves with the higher swl's) for sand management purposes.

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Table 1
Wave Heights for Existing Conditions

Experimental Wave			Wave Height (ft) at Indicated Gauge Location													
Direction Azimuth (deg)	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
swl = +1.6 ft																
227	9	1 (3.3)	3.6	3.8	3.7	3.0	1.8	0.8	1.4	0.1	0.4	0.6	1.9	2.8	2.7	2.7
		2 (6.6)	6.3	8.4	8.1	6.6	4.2	1.9	3.2	0.3	0.6	0.9	2.6	4.5	5.9	3.2
	12	3 (9.8)	6.3	13.8	14.0	11.6	8.5	4.7	3.5	0.4	0.7	1.0	2.7	4.8	9.0	4.2
	24	3 (9.8)	6.6	14.6	15.7	13.9	10.0	7.4	3.9	0.5	0.8	1.2	3.1	5.2	10.0	4.6
212	9	1 (3.3)	2.5	4.3	3.4	3.3	1.9	0.9	2.8	0.1	0.5	0.7	1.8	3.1	2.8	2.4
		2 (6.6)	5.1	9.0	7.3	6.9	4.3	2.2	3.1	0.3	0.6	1.0	2.4	4.2	5.9	2.8
		3 (9.8)	5.6	12.0	10.5	10.0	6.5	5.3	3.3	0.4	0.7	1.1	2.5	4.2	7.7	3.3
	12	1 (3.3)	2.8	5.3	3.9	3.8	2.5	1.2	3.1	0.2	0.6	0.9	2.2	4.0	3.1	2.8
		2 (6.6)	5.7	11.3	8.2	8.0	6.1	3.5	3.3	0.4	0.7	1.1	2.6	4.5	7.6	3.3
		3 (9.8)	6.0	14.6	12.3	12.2	9.8	7.3	3.5	0.4	0.7	1.1	2.7	4.5	8.7	3.8
	15	1 (3.3)	3.3	5.7	4.2	4.2	4.0	2.0	3.3	0.3	0.6	1.0	2.4	4.5	3.9	3.1
		2 (6.6)	6.0	12.1	13.3	12.3	9.0	5.2	3.4	0.4	0.7	1.1	2.7	4.6	8.7	3.6
		3 (9.8)	6.1	14.9	13.6	12.8	12.0	7.5	3.7	0.4	0.8	1.2	2.8	4.7	9.1	3.9
	24	1 (3.3)	2.7	6.4	4.7	5.2	5.5	3.2	3.6	0.3	0.6	1.0	2.4	4.2	4.6	3.1
		2 (6.6)	5.1	12.4	11.4	11.3	10.0	6.5	3.6	0.4	0.7	1.2	2.9	4.6	9.5	3.8
		3 (9.8)	5.5	13.3	14.1	14.1	11.1	7.5	4.0	0.4	0.7	1.2	3.0	4.6	9.6	4.2

(Sheet 1 of 3)

Table 1 (Continued)

Experimental Wave			Wave Height (ft) at Indicated Gauge Location													
Direction Azimuth (deg)	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
swl = +1.6 ft																
182	9	1 (3.3)	1.0	3.7	3.6	3.2	2.9	2.3	3.2	0.1	0.6	0.9	1.9	3.7	3.7	2.8
		2 (6.6)	3.1	7.9	8.0	6.7	6.6	5.0	3.8	0.3	0.7	1.1	2.6	4.7	8.0	3.2
		3 (9.8)	4.9	13.5	11.3	9.7	9.8	6.6	4.0	0.4	0.7	1.2	2.7	4.9	9.2	3.6
	12	1 (3.3)	1.1	4.0	3.9	3.7	3.8	2.5	3.5	0.2	0.6	0.9	2.2	4.3	5.3	3.0
		2 (6.6)	2.9	8.6	8.8	7.2	8.4	5.9	4.0	0.4	0.8	1.2	2.9	5.2	9.1	3.7
		3 (9.8)	4.9	11.7	13.0	11.3	12.2	7.6	4.3	0.4	0.8	1.2	2.9	5.4	9.2	4.2
	15	1 (3.3)	1.2	4.8	4.8	4.1	5.0	3.1	3.8	0.3	0.7	1.0	2.5	4.8	6.5	3.2
		2 (6.6)	3.6	10.3	10.4	8.1	10.7	7.1	4.1	0.4	0.7	1.2	2.9	5.0	9.8	3.7
		3 (9.8)	4.5	13.3	14.8	12.3	14.5	8.3	4.7	0.4	0.8	1.2	2.9	5.3	9.8	4.1
	24	1 (3.3)	1.4	5.6	4.5	4.3	5.9	3.9	3.9	0.3	0.7	1.0	2.5	4.6	6.8	3.2
		2 (6.6)	3.1	12.4	12.1	10.0	12.8	7.1	4.3	0.3	0.8	1.2	3.1	5.3	9.3	4.0
		3 (9.8)	4.6	13.3	14.4	14.2	15.2	8.6	4.6	0.4	0.8	1.2	3.2	5.4	9.2	4.5
137	9	1 (3.3)	3.3	2.5	2.2	2.4	3.9	3.1	3.2	0.2	0.5	0.7	1.8	3.2	3.8	2.4
	12	2 (6.6)	4.6	8.2	5.1	5.6	9.4	9.8	3.5	0.3	0.6	0.9	2.4	4.8	7.3	2.9
		3 (9.8)	5.9	10.5	6.9	9.4	15.3	10.5	3.8	0.3	0.6	1.0	2.6	5.0	8.2	3.3

Table 1 (Concluded)

Experimental Wave			Wave Height (ft) at Indicated Gauge Location													
Direction Azimuth (deg)	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
swl = +13.0 ft																
257	12	6 (19.7)	11.0	17.5	19.2	20.1	8.3	4.3	6.8	1.6	1.3	1.4	4.3	11.4	14.6	11.0
	24	3 (9.8)	11.2	14.7	16.3	16.6	7.8	4.4	4.7	2.3	1.4	1.5	4.4	12.0	13.7	10.6
137	12	6 (19.7)	13.8	15.6	16.0	18.6	22.9	18.5	10.2	1.7	1.1	1.6	4.6	11.8	13.6	9.4
	24	3 (9.8)	14.5	11.0	9.7	10.4	13.8	14.4	10.3	1.6	1.0	1.4	4.3	10.3	13.8	9.2

(Sheet 3 of 3)

Table 2
Wave Heights for Plans 1-12, swl = +1.6 ft

	Experimental Wave		Wave Height (ft) at Indicated Gauge Location													
Plan	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
137 deg																
1	12	2 (6.6)	4.2	7.3	4.4	5.4	8.1	6.6	2.7	0.3	0.5	0.8	2.4	5.1	8.3	4.3
2	12	2 (6.6)	4.6	7.4	4.5	5.6	4.3	1.5	1.6	0.3	0.6	0.9	2.6	5.0	8.8	4.3
3	12	2 (6.6)	4.6	7.4	4.6	5.6	9.0	2.6	1.6	0.3	0.5	0.8	2.4	4.9	7.9	4.1
4	12	2 (6.6)	1.0	7.4	4.6	3.2	2.3	0.8	0.8	0.3	0.8	1.0	1.2	4.7	1.3	3.5
5	12	2 (6.6)	1.7	7.1	4.5	5.4	7.9	2.1	1.2	0.2	0.2	0.1	2.1	4.8	2.1	3.6
6	12	2 (6.6)	1.6	7.1	4.6	5.3	7.6	2.0	1.1	0.2	0.2	0.1	2.2	4.9	2.1	3.7
227 deg																
5	12	2 (6.6)	5.5	10.3	9.6	8.4	6.5	2.7	3.8	0.5	0.5	0.2	4.7	4.4	4.9	3.0
6	12	2 (6.6)	4.5	10.1	9.8	8.6	4.7	2.3	3.2	0.4	0.3	0.2	4.9	4.5	4.2	3.0
7	12	2 (6.6)	4.2	10.2	10.1	8.4	4.2	2.3	2.9	0.5	0.3	0.1	4.7	4.4	4.1	3.0
8	12	2 (6.6)	4.9	10.2	10.1	8.1	4.4	2.5	3.1	0.4	0.3	0.2	4.7	4.4	4.7	3.0
9	12	2 (6.6)	5.4	10.0	9.9	8.0	6.6	2.5	3.7	0.5	0.4	0.2	2.7	4.8	5.0	3.2
10	9	2 (6.6)	3.8	8.5	8.3	6.7	2.4	1.1	2.5	0.2	0.3	0.1	2.3	4.4	3.2	2.9
10	12	1 (3.3)	1.9	4.7	4.4	3.9	1.9	0.7	1.3	0.1	0.1	0.1	0.9	3.5	1.8	2.9
10	12	2 (6.6)	4.1	10.3	9.7	8.7	4.1	2.1	2.8	0.4	0.3	0.2	2.0	4.9	4.2	3.2
11	12	2 (6.6)	3.4	10.4	10.2	7.8	3.3	1.9	2.2	0.3	0.4	0.1	1.6	4.9	3.6	3.2

(Continued)

Table 2 (Concluded)

Plan	Experimental Wave		Wave Height at indicated Gauge Locaion													
	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
182 deg																
9	9	1 (3.3)	1.2	3.7	3.5	3.2	3.0	1.9	0.6	0.1	0.1	0.1	0.5	3.3	1.9	2.8
9	9	2 (6.6)	2.6	8.2	7.3	6.8	6.2	4.0	1.5	0.3	0.3	0.2	1.0	4.7	4.3	3.1
9	12	1 (3.3)	1.3	3.8	3.9	3.6	3.6	1.6	0.9	0.1	0.1	0.1	0.7	3.4	2.2	2.8
9	12	2 (6.6)	2.7	8.5	8.1	7.6	8.1	3.5	2.0	0.4	0.3	0.2	1.3	5.3	4.5	3.4
11	9	1 (3.3)	1.3	3.6	3.4	3.1	2.0	1.7	0.7	0.1	0.1	0.1	0.5	3.0	1.8	2.7
11	9	2 (6.6)	3.0	7.6	7.1	6.5	3.5	3.4	1.6	0.3	0.3	0.1	1.0	4.6	4.1	2.9
11	12	1 (3.3)	1.5	3.8	3.8	3.7	2.3	1.5	0.9	0.1	0.1	0.1	0.7	3.5	2.1	2.8
11	12	2 (6.6)	3.3	8.4	8.5	8.2	5.7	3.5	2.1	0.4	0.4	0.2	1.4	5.2	4.5	4.0
137 deg																
9	9	1 (3.3)	1.1	2.8	2.6	2.5	3.6	1.2	0.5	0.1	0.1	0.1	0.5	3.1	0.8	2.6
9	9	2 (6.6)	2.1	6.0	5.4	5.9	7.9	2.3	1.0	0.2	0.2	0.1	1.0	5.0	1.5	3.1
9	12	1 (3.3)	1.1	3.0	2.2	2.2	3.2	1.1	0.5	0.1	0.1	0.1	0.5	4.0	1.2	2.9
12	9	1 (3.3)	1.1	2.5	2.2	2.5	3.7	1.6	0.5	0.1	0.1	0.1	0.6	3.1	1.0	2.5
12	9	2 (6.6)	2.0	5.7	4.9	5.7	8.4	3.1	1.1	0.2	0.2	0.1	1.0	4.9	1.9	3.1
12	12	1 (3.3)	1.5	3.1	2.3	2.4	3.4	1.8	0.6	0.1	0.1	0.1	0.5	4.0	1.4	2.9

Table 3
Wave Heights for Plans 13-16

	Experimental Wave			Wave Height (ft) at Indicated Gauge Location													
Plan	Direction Azimuth (deg)	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
	swl = +1.6 ft																
13	137	12	1 (3.3)	1.0	3.3	2.2	2.2	3.0	1.1	0.5	0.1	0.1	0.1	0.5	3.7	1.2	1.6
13	137	12	2 (6.6)	1.7	7.0	4.6	5.4	7.2	2.3	1.1	0.3	0.1	0.1	0.9	5.1	2.4	3.1
13	137	12	5 (16.4)	3.6	11.4	11.3	14.8	15.8	4.7	2.5	0.9	1.0	0.5	2.1	5.5	4.6	5.1
14	137	12	5 (16.4)	3.6	12.0	11.6	14.7	14.7	4.5	2.4	1.0	1.0	0.5	2.1	5.5	4.3	5.0
14	227	9	1 (3.3)	1.4	3.7	3.9	3.2	1.1	0.4	0.9	0.1	0.1	0.1	0.8	2.7	1.2	1.7
14	227	9	2 (6.6)	3.1	8.0	8.3	6.8	2.1	1.0	2.0	0.2	0.1	0.1	1.8	4.5	2.8	3.8
14	227	12	1 (3.3)	1.5	4.5	4.3	3.6	1.7	0.7	1.0	0.1	0.1	0.1	0.7	3.3	1.6	1.7
14	227	12	2 (6.6)	3.5	9.9	10.0	8.2	3.6	2.0	2.4	0.4	0.3	0.1	1.8	4.7	3.9	4.2
14	227	12	5 (16.4)	6.3	15.3	17.5	16.2	6.7	4.7	3.8	0.9	0.8	0.5	3.4	5.5	7.0	8.0
15	227	9	1 (3.3)	1.7	3.7	3.9	3.1	1.2	0.5	1.2	0.1	0.1	0.1	1.1	2.9	1.4	2.1
15	227	9	2 (6.6)	3.7	8.0	8.2	6.7	2.4	1.1	2.4	0.2	0.2	0.1	2.3	4.3	3.2	4.4
16	227	9	1 (3.3)	1.3	3.7	3.8	2.7	1.0	0.5	0.8	0.1	0.1	0.1	0.7	3.1	1.1	1.5
16	227	9	2 (6.6)	2.8	7.6	7.7	5.7	1.9	1.0	1.8	0.1	0.1	0.1	1.5	5.0	2.5	3.4
16	227	12	1 (3.3)	1.2	4.4	4.6	3.1	1.5	0.7	0.9	0.1	0.1	0.1	0.6	3.7	1.4	1.5
16	227	12	2 (6.6)	2.8	9.8	9.5	6.4	3.1	1.6	1.9	0.3	0.2	0.2	1.5	5.4	3.1	3.3

(Continued)

Table 3 (Concluded)

	Experimental Wave			Wave Height (ft) at Indicated Gauge Location													
Plan	Direction Azimuth (deg)	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
swl = +1.6 ft (Continued)																	
14	182	9	1 (3.3)	1.5	3.2	3.3	3.1	2.2	1.7	0.8	0.1	0.1	0.1	0.5	3.6	1.9	2.2
14	182	9	2 (6.6)	3.0	7.2	7.3	6.7	5.0	3.5	1.7	0.3	0.3	0.1	1.1	4.4	3.9	4.6
14	182	12	1 (3.3)	1.4	3.5	4.0	3.5	2.5	1.4	0.9	0.1	0.1	0.1	0.7	4.2	1.9	2.1
14	182	12	2 (6.6)	3.0	7.8	8.7	7.6	5.7	3.1	1.9	0.4	0.4	0.2	1.3	5.0	4.1	4.4
14	182	12	5 (16.4)	5.6	13.9	16.9	16.6	14.7	5.8	3.9	1.0	1.2	0.6	3.0	5.8	7.0	8.1
swl = + 13.0 ft																	
14	182	12	6 (19.7)	8.8	17.2	22.5	20.8	22.0	11.3	7.1	2.4	1.9	2.3	9.2	12.8	10.2	9.0
14	227	12	6 (19.7)	11.2	20.2	21.4	20.0	9.7	6.0	6.9	1.5	1.4	1.5	7.7	12.3	8.7	12.4
16	227	12	6 (19.7)	10.9	18.9	20.9	18.8	9.7	5.8	6.8	1.7	1.4	1.6	7.6	12.4	9.0	12.2

Table 4
Wave Heights for Plan 17, swl = +1.6 ft

Experimental Wave		Wave Height (ft) at Indicated Gauge Location													
Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
227 deg															
9	1 (3.3)	2.0	3.7	3.7	3.0	1.9	0.6	1.4	0.1	0.1	0.1	4.7	2.6	1.4	2.2
	2 (6.6)	5.0	8.0	8.1	6.7	4.4	1.3	3.5	0.4	0.3	0.2	6.6	4.2	3.6	5.2
12	1 (3.3)	2.6	4.3	4.4	3.5	2.7	0.8	1.7	0.2	0.1	0.1	4.8	3.2	1.9	2.7
	2 (6.6)	6.4	9.8	9.9	7.4	6.3	2.0	4.6	0.6	0.6	0.2	7.0	4.3	4.5	6.5
12	5 (16.4)	9.9	15.1	17.2	16.3	9.6	8.2	5.5	1.0	1.2	0.6	7.1	4.8	9.7	10.8
182 deg															
9	1 (3.3)	2.2	3.2	3.5	3.0	2.7	2.1	1.6	0.2	0.1	0.1	3.2	3.5	2.8	2.9
	2 (6.6)	6.1	7.0	7.2	7.1	5.2	5.7	4.0	0.6	0.6	0.3	6.9	4.6	7.4	8.0
12	1 (3.3)	2.8	3.4	3.8	3.4	3.2	2.0	2.0	0.3	0.2	0.2	5.5	4.3	3.4	3.3
	2 (6.6)	7.2	7.5	8.5	7.9	6.7	6.1	5.1	0.9	0.8	0.5	8.4	5.1	8.6	8.6
12	5 (16.4)	10.6	13.9	17.0	17.0	14.7	11.0	6.9	1.3	1.5	0.9	8.7	5.7	11.2	12.9
137 deg															
9	1 (3.3)	2.5	2.5	2.3	2.5	3.6	2.6	2.6	0.3	0.2	0.1	5.0	2.8	2.2	2.2
	2 (6.6)	6.2	5.7	4.6	5.6	8.8	7.1	7.2	0.8	0.7	0.4	6.5	4.3	5.6	5.4
12	1 (3.3)	2.8	3.1	2.2	2.3	3.4	2.6	2.9	0.5	0.3	0.2	5.9	3.5	2.4	2.8
	2 (6.6)	5.9	7.1	4.5	5.6	8.9	8.4	7.7	1.0	0.7	0.6	6.9	4.5	5.5	6.7
12	5 (16.4)	10.9	12.7	12.3	15.2	18.4	13.2	8.1	1.3	1.7	1.3	7.9	5.2	9.6	11.4

Table 5
Wave Heights for Plan 19

Experimental Wave			Wave Height (ft) at Indicated Gauge Location													
Direction Azimuth (deg)	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
swl = +1.6 ft																
227	9	1 (3.3)	1.6	3.8	4.0	2.9	1.3	0.4	1.1	0.1	0.1	0.1	0.4	3.4	1.4	2.0
		2 (6.6)	3.4	8.0	8.1	6.3	2.3	1.0	2.4	0.3	0.2	0.2	1.3	7.4	2.9	4.1
	12	1 (3.3)	1.7	4.5	4.1	3.8	2.0	0.8	1.2	0.1	0.1	0.1	0.6	3.8	1.7	2.0
		2 (6.6)	3.8	9.8	9.6	8.3	3.8	2.0	2.7	0.4	0.4	0.3	1.6	8.1	3.7	4.6
		5 (16.4)	6.5	15.2	16.9	16.3	6.8	4.4	4.3	0.7	1.0	0.7	3.0	16.3	6.8	8.4
182	9	1 (3.3)	1.4	3.5	3.4	3.2	2.2	1.8	0.9	0.1	0.1	0.1	0.5	3.3	1.9	2.1
		2 (6.6)	2.7	7.3	7.4	6.6	5.5	3.6	1.8	0.4	0.4	0.1	1.0	6.9	3.8	4.0
	12	1 (3.3)	1.6	3.8	3.8	3.6	2.8	1.6	1.1	0.2	0.1	0.1	0.7	3.4	2.1	2.2
		2 (6.6)	3.1	8.3	8.4	7.5	6.1	3.2	2.2	0.5	0.5	0.4	1.6	7.1	4.1	4.3
		5 (16.4)	6.1	14.7	16.6	16.7	14.1	5.8	4.0	1.1	1.2	0.9	3.0	15.7	7.1	8.1
137	9	1 (3.3)	1.0	2.7	2.4	2.4	3.2	1.4	0.6	0.2	0.1	0.1	0.7	2.9	0.9	1.4
		2 (6.6)	1.9	5.6	4.7	5.8	8.4	2.6	1.6	0.5	0.2	0.2	1.3	5.7	1.8	2.7
	12	1 (3.3)	1.3	3.3	2.5	2.5	3.5	1.4	0.6	0.3	0.1	0.1	1.0	3.2	1.4	1.9
		2 (6.6)	1.9	6.8	5.2	5.7	7.3	2.4	1.4	0.4	0.4	0.2	1.5	6.1	2.6	3.0
		5 (16.4)	3.9	11.9	11.9	14.5	15.4	4.9	2.8	0.8	1.0	0.6	2.4	11.6	4.6	5.3

(Continued)

Table 5 (Concluded)

Experimental Wave			Wave Height (ft) at Indicated Gauge Location													
Direction Azimuth (deg)	Period (sec)	Height m (ft)	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6	Gauge 7	Gauge 8	Gauge 9	Gauge 10	Gauge 11	Gauge 12	Gauge 13	Gauge 14
swl = +13.0 ft																
227	12	6 (19.7)	11.4	19.7	21.7	18.6	9.3	5.6	7.5	2.2	1.4	1.6	7.3	19.4	8.1	12.5
182	12	6 (19.7)	8.2	18.4	20.3	19.0	19.6	10.8	7.2	2.8	1.7	2.1	9.0	18.3	10.1	8.8
137	12	6 (19.7)	10.4	14.5	15.7	16.5	17.7	13.1	9.0	2.1	1.1	1.4	9.8	12.7	10.2	9.5

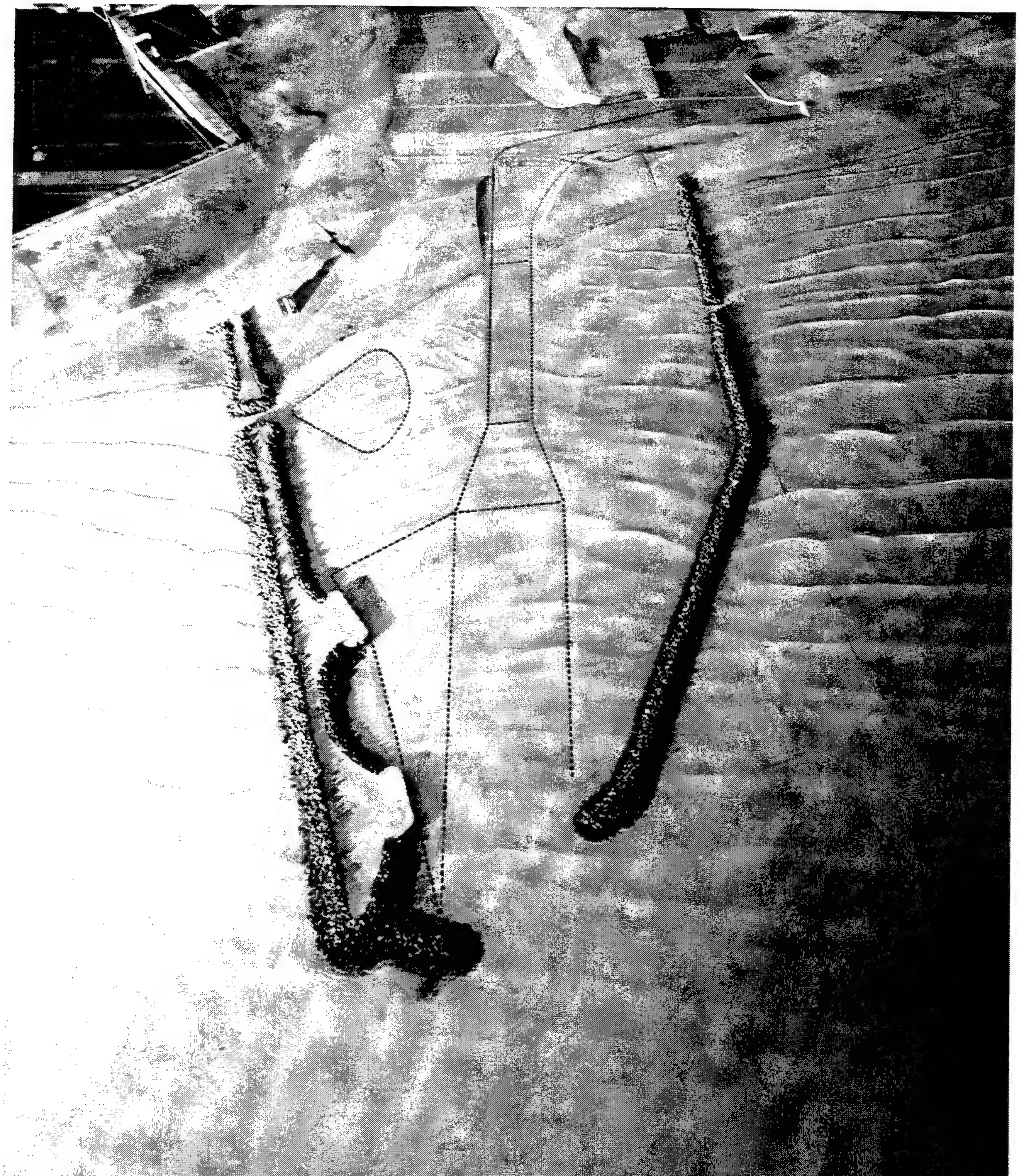


Photo 1. Typical wave patterns for Plan 19; 9-sec, 2-m (6.6-ft) waves from 227 deg; swl = +0.5-m (+1.6-ft)

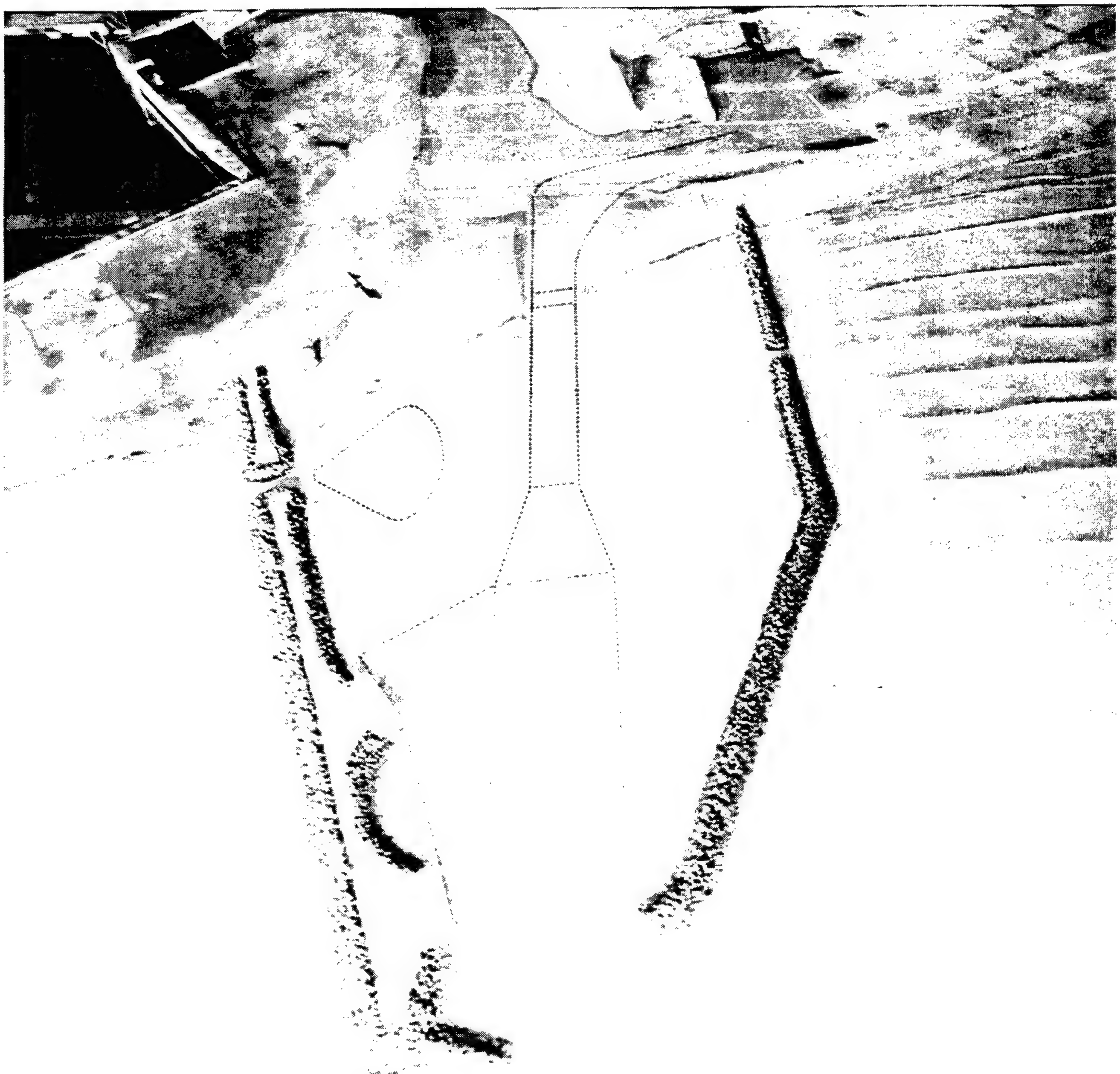


Photo 2. Typical wave patterns for Plan 19; 12-sec, 1-m (3.3-ft) waves from 227 deg; swl = +0.5-m (+1.6-ft)

Photo 3. Typical wave patterns for Plan 19; 12-sec, 5-m ((16.4-ft) waves from 227 deg; swl = +0.5-m (+1.6-ft)

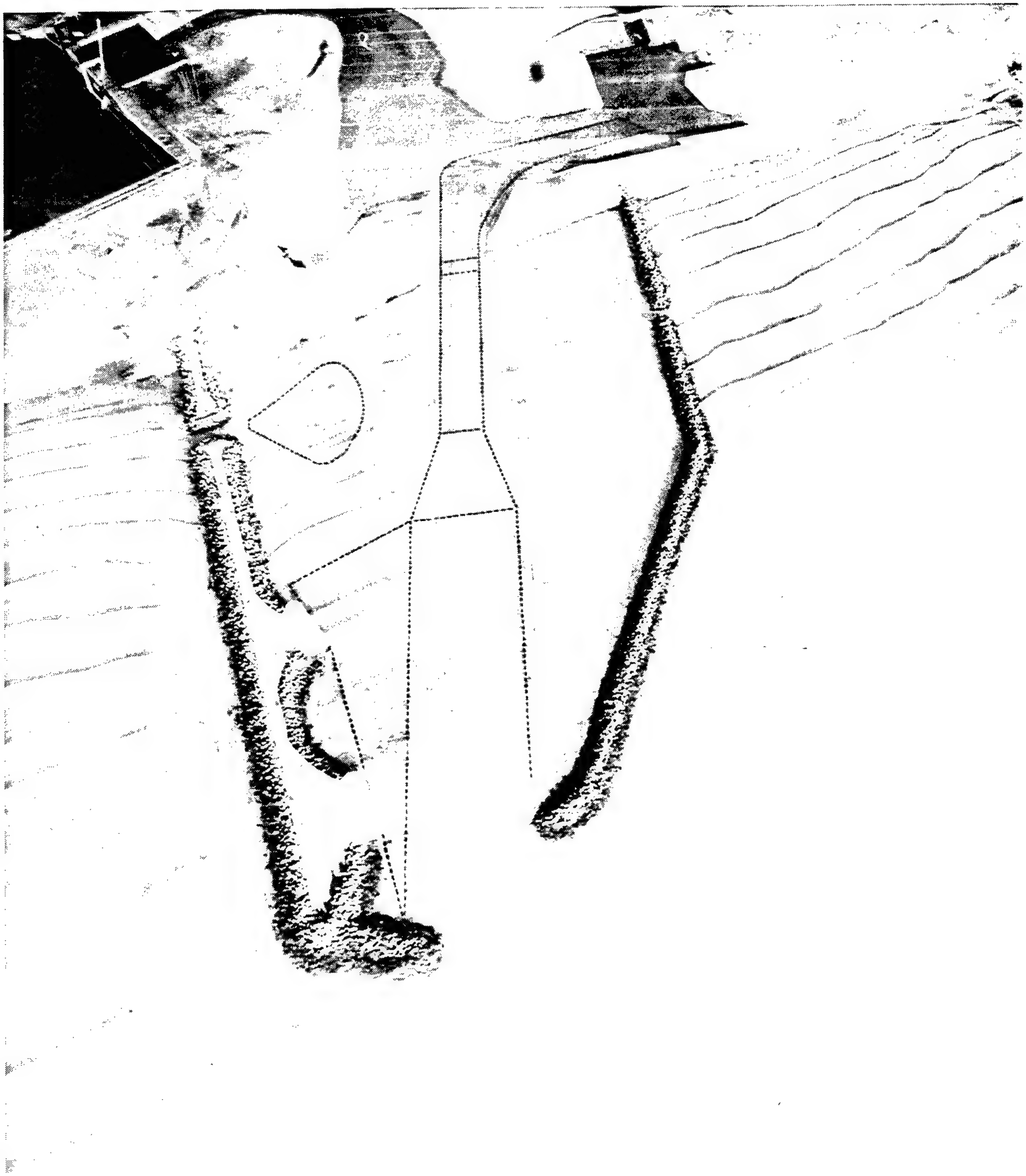


Photo 4. Typical wave patterns for Plan 19; 9-sec, 2-m (6.6-ft) waves from 182 deg; swl = +0.5-m (+1.6-ft)

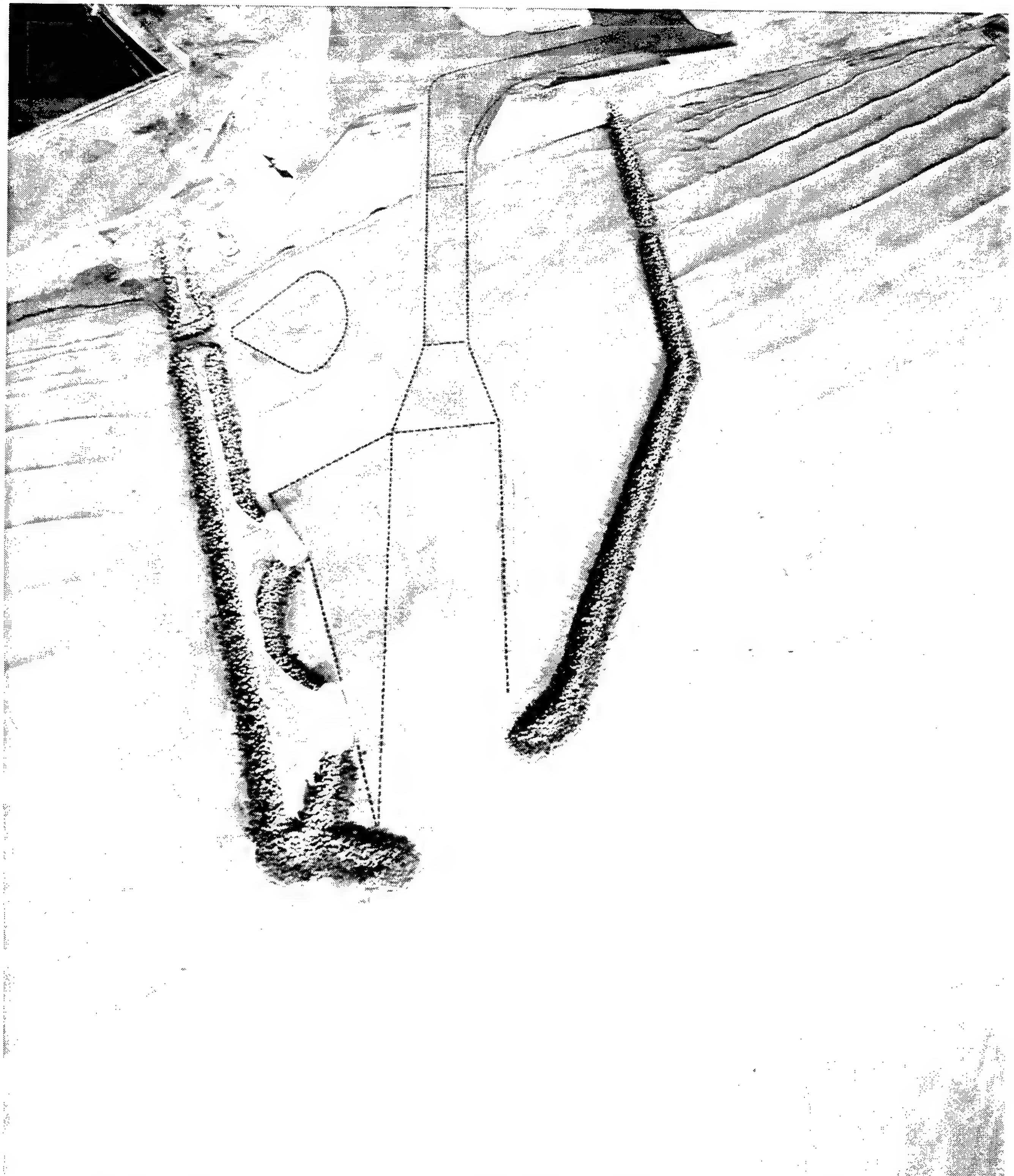


Photo 5. Typical wave patterns for Plan 19; 12-sec, 1-m (3.3-ft) waves from 182 deg; swl = +0.5-m (+1.6-ft)

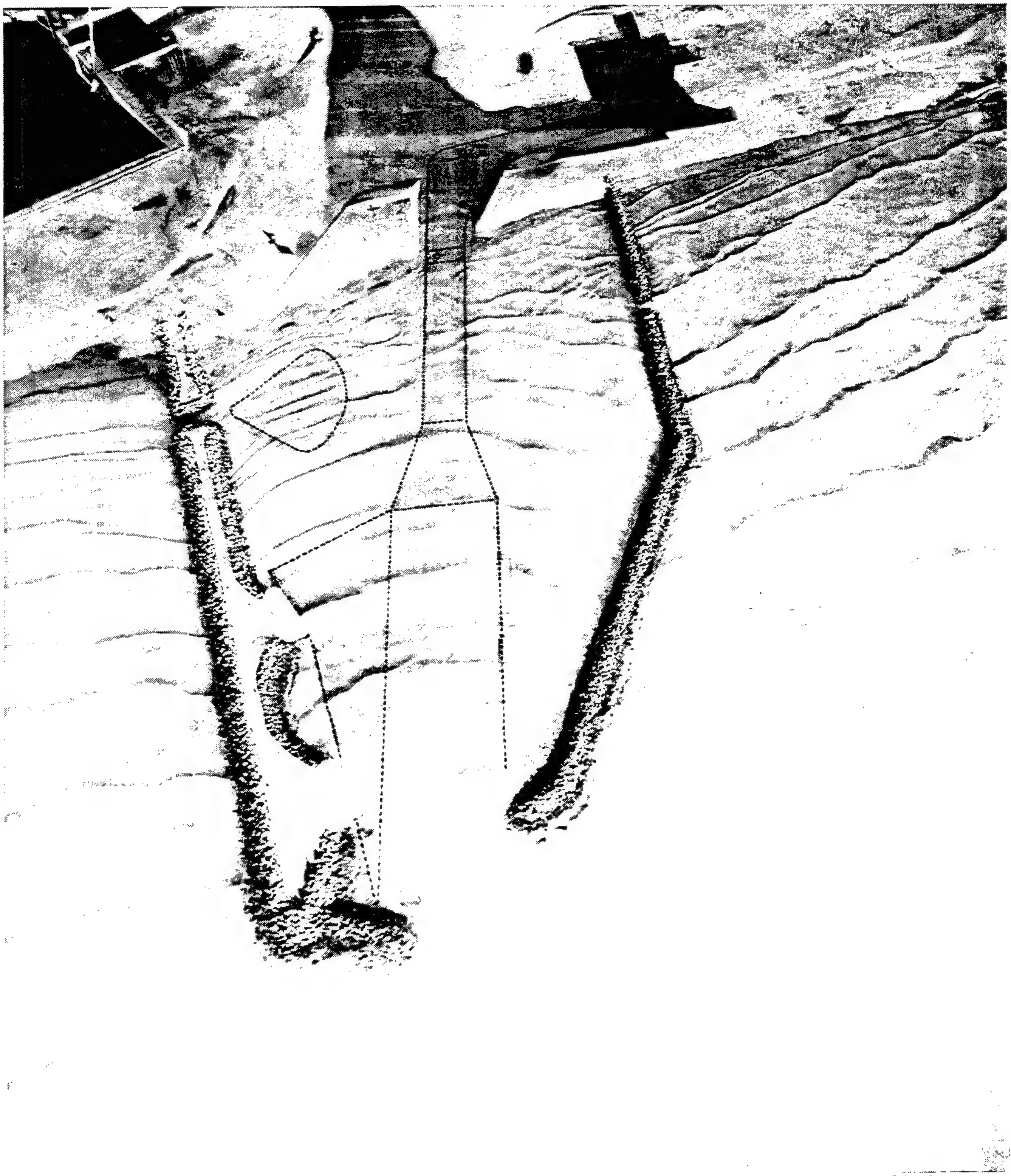


Photo 6. Typical wave patterns for Plan 19; 12-sec, 5-m (16.4-ft) waves from 182 deg; swl = +0.5-m (+1.6-ft)

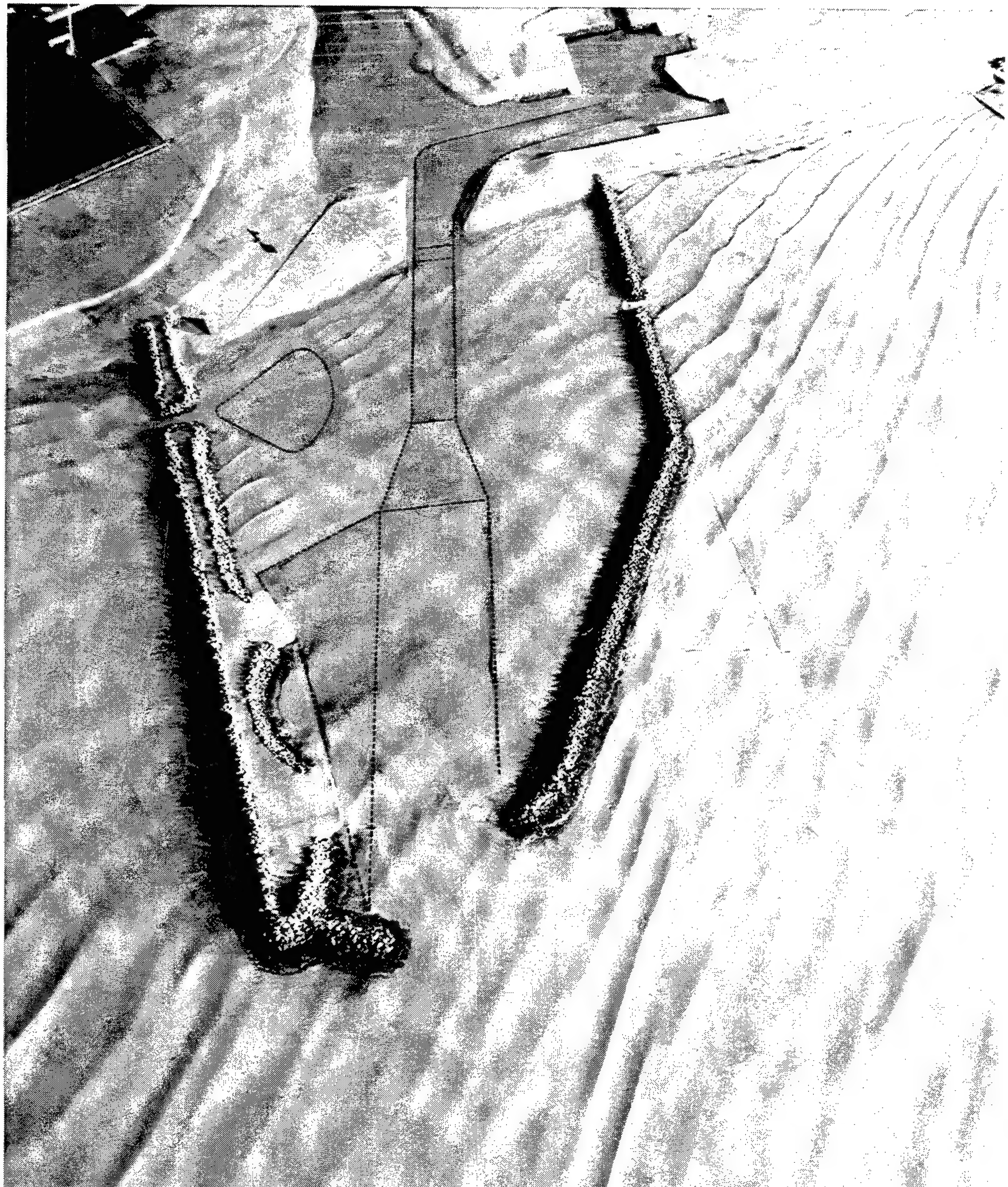


Photo 7. Typical wave patterns for Plan 19; 9-sec, 2-m (6.6-ft) waves from 137 deg; swl = +0.5-m (+1.6-ft)

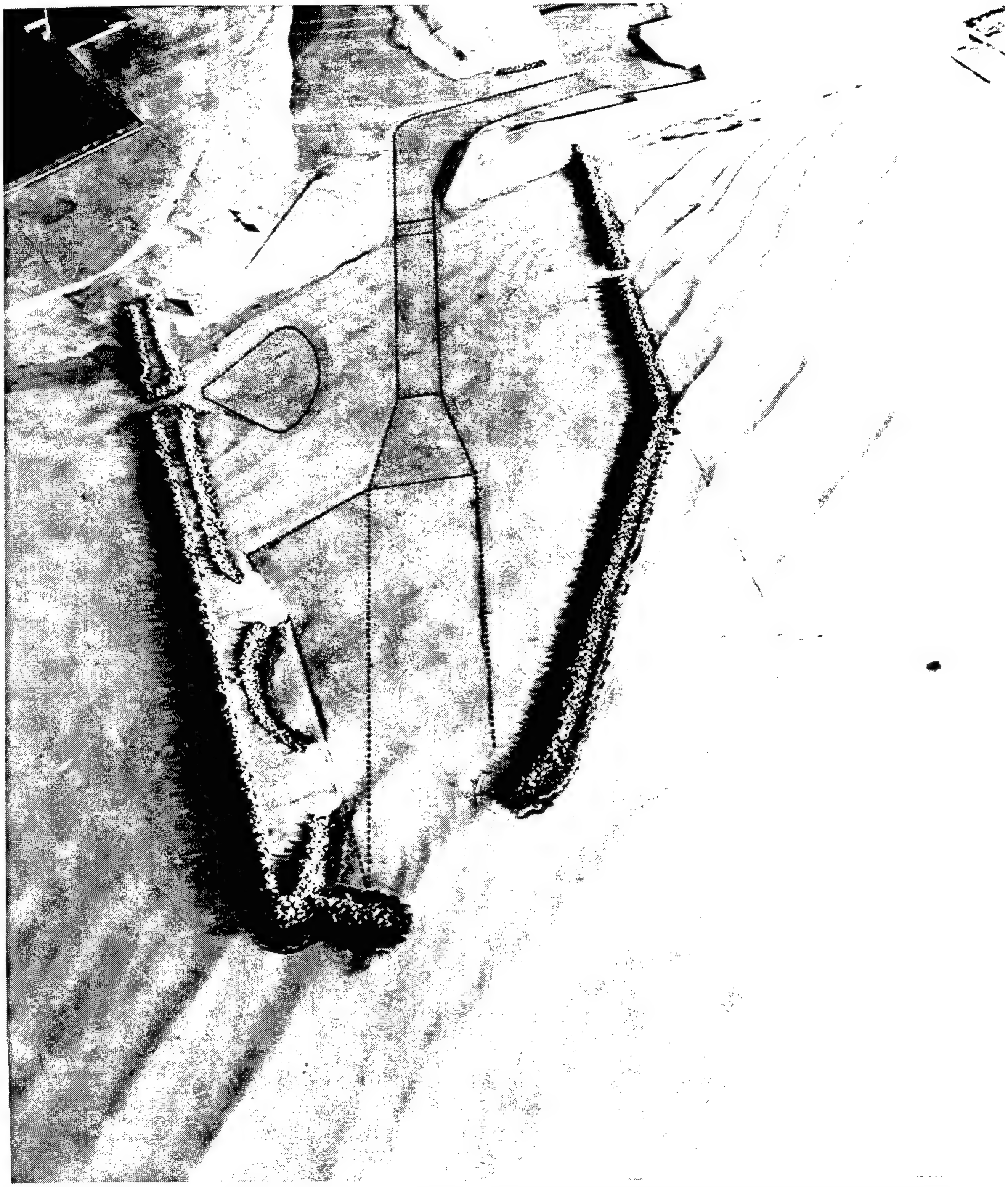


Photo 8. Typical wave patterns for Plan 19; 12-sec, 1-m (3.3-ft) waves from 137 deg; swl = +0.5-m (+1.6-ft)

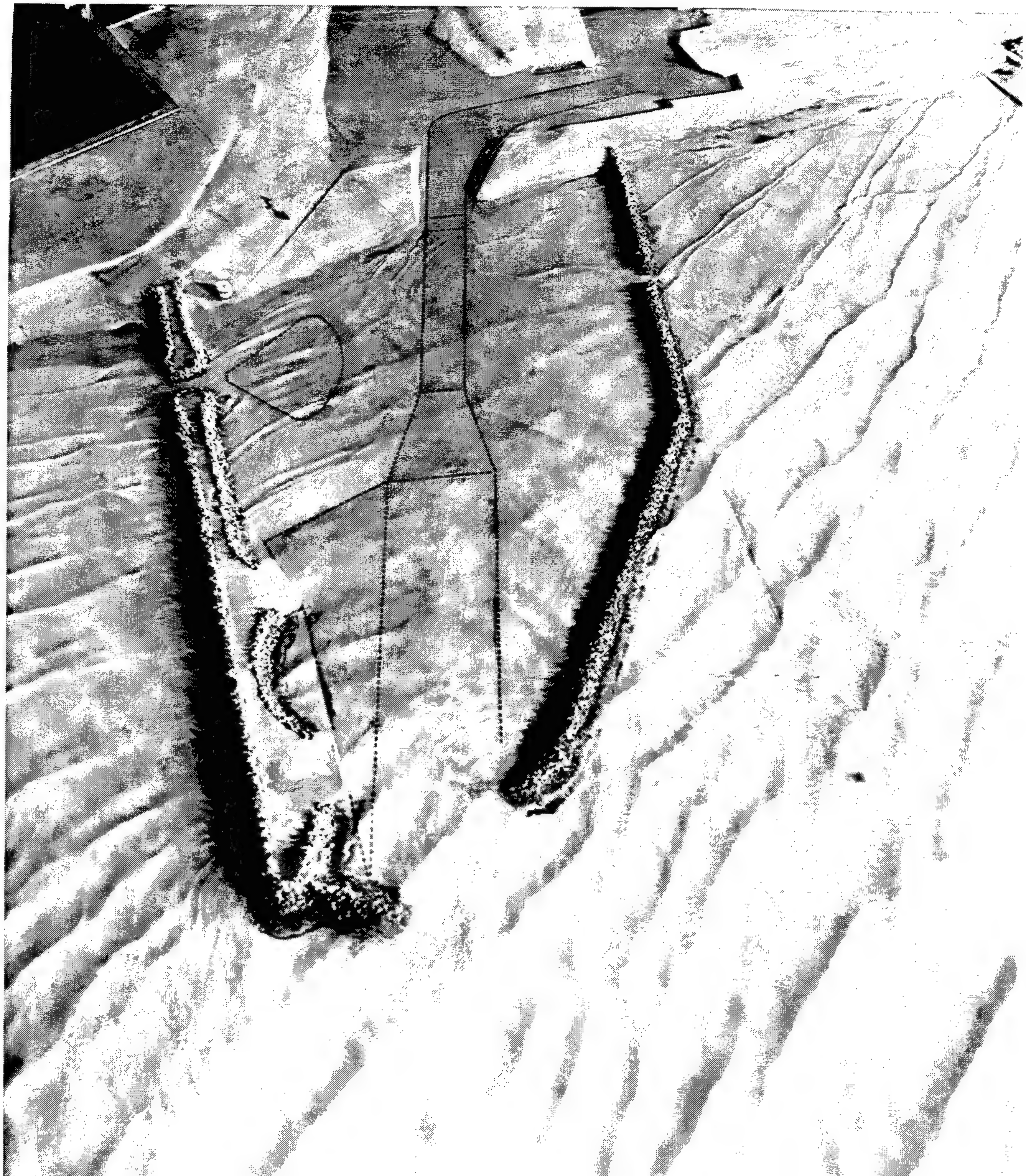
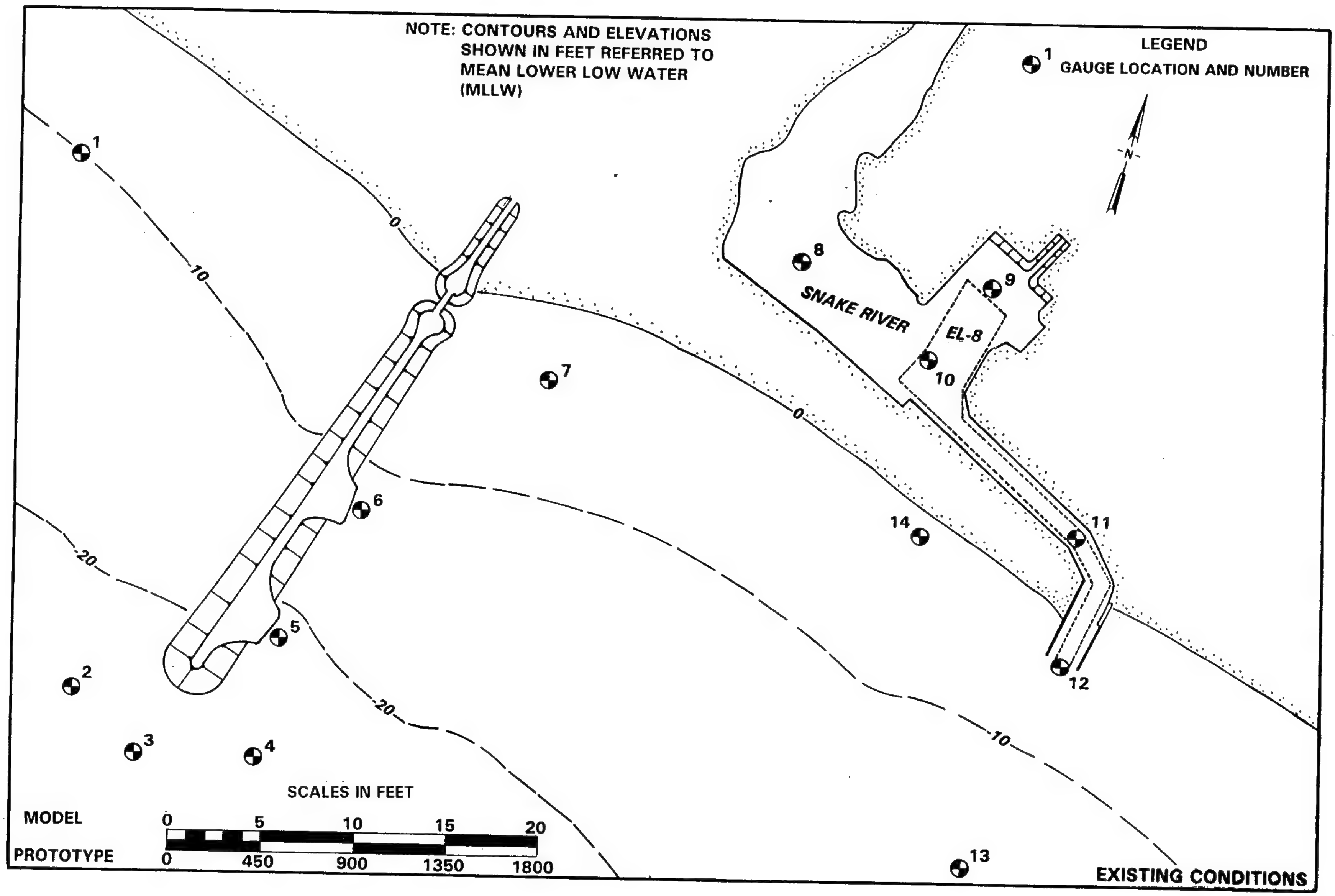
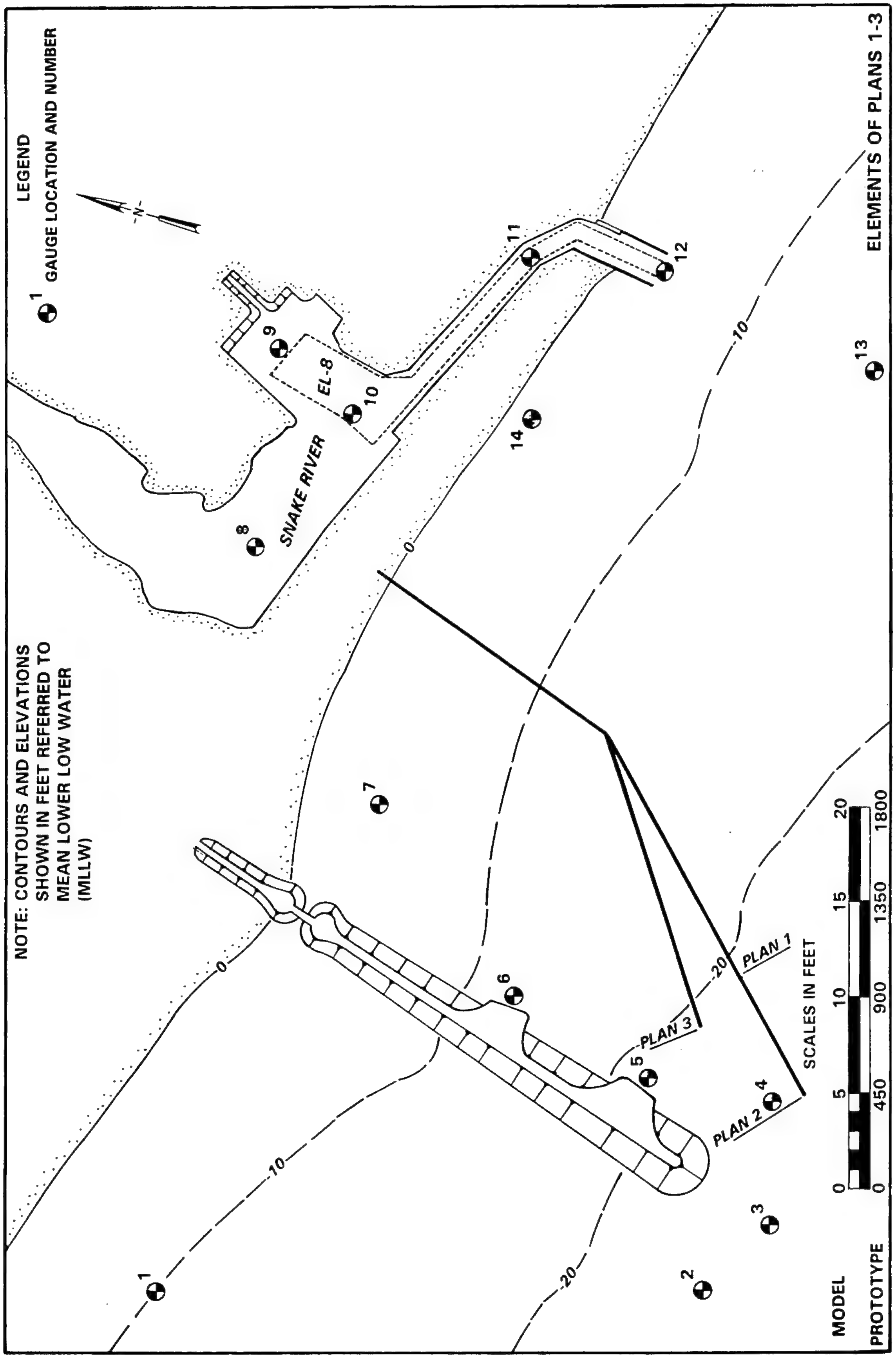


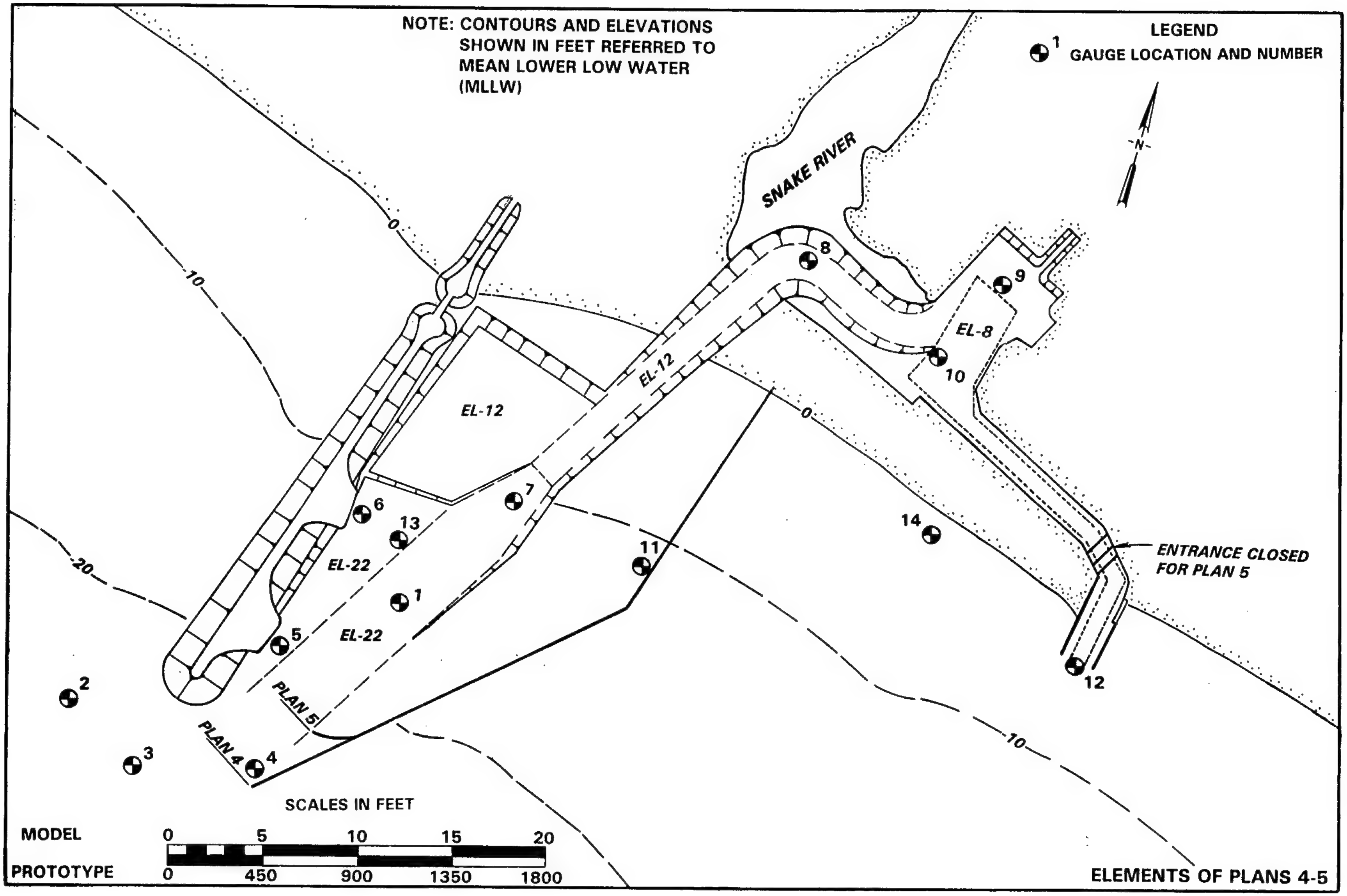
Photo 9. Typical wave patterns for Plan 19; 12-sec, 5-m (16.4-ft) waves from 137 deg; swl = +0.5-m (+1.6-ft)

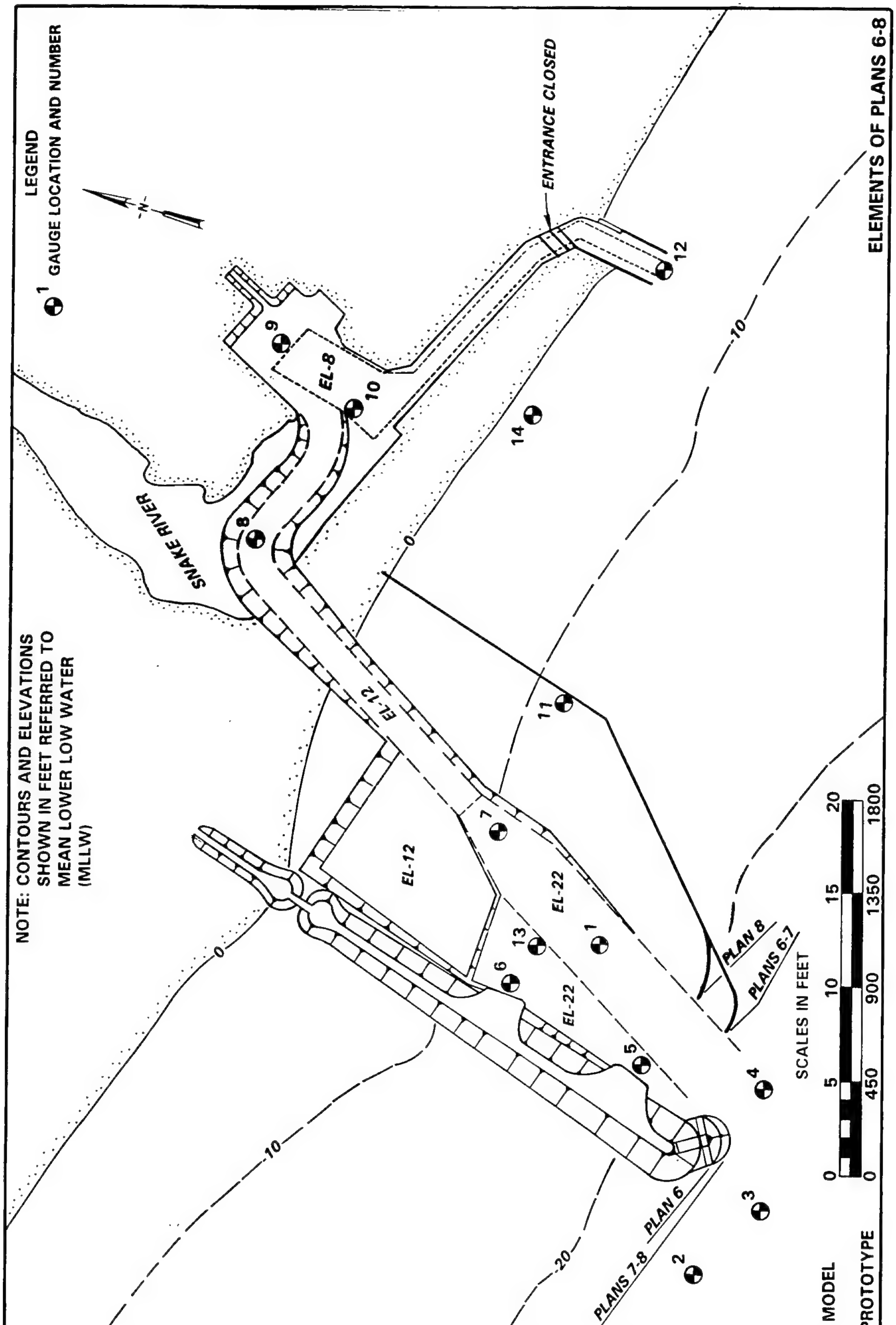


NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
1 GAUGE LOCATION AND NUMBER
N
SNAKE RIVER
EL-8
0
10
20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
SCALES IN FEET
MODEL
0
5
10
15
20
PROTOTYPE
0
450
900
1350
1800
EXISTING CONDITIONS

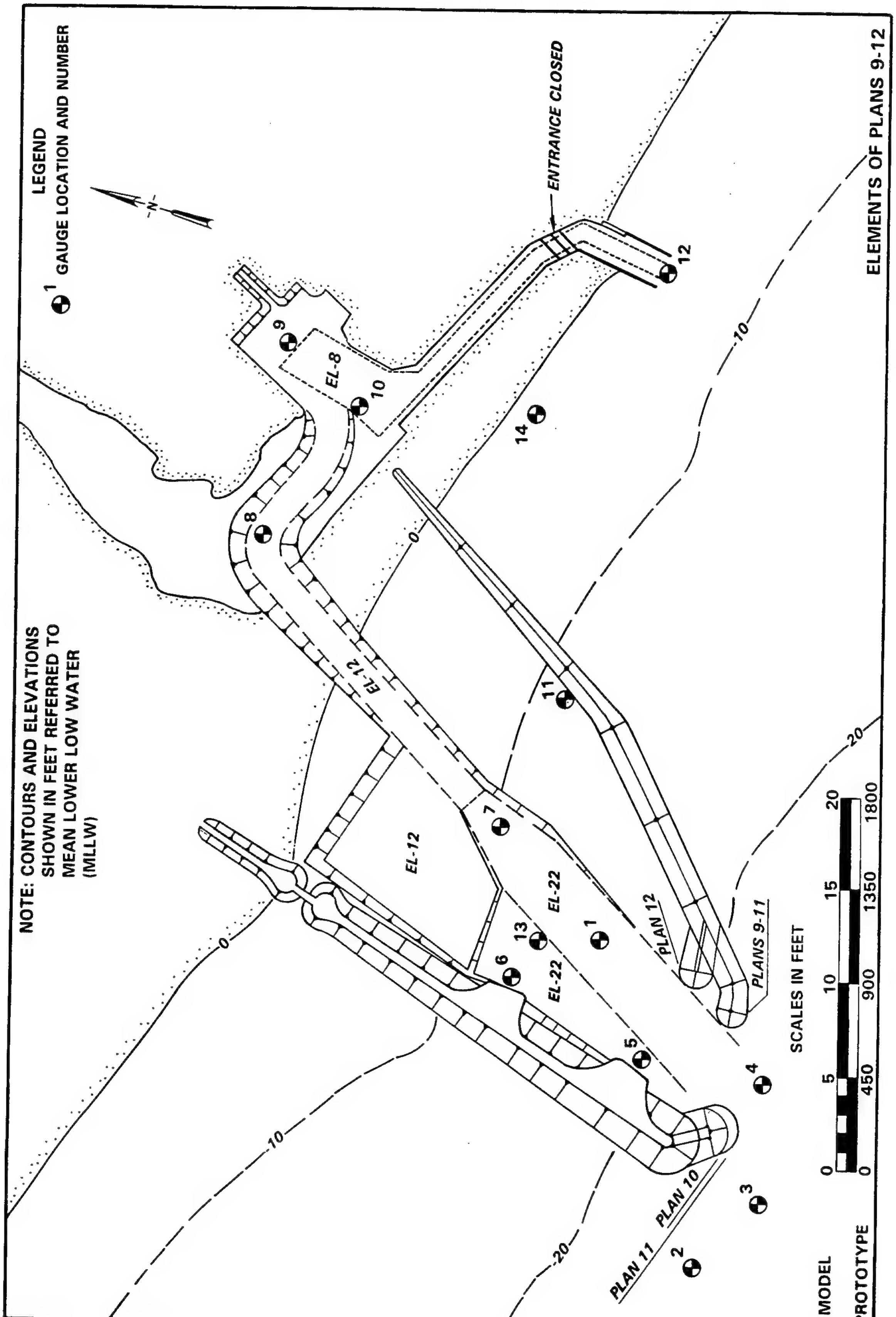
Plate 1


NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
GAUGE LOCATION AND NUMBER
SNAKE RIVER
EL-8
PLAN 1
PLAN 2
PLAN 3
SCALES IN FEET
MODEL
PROTOTYPE
0 5 10 15 20
0 450 900 1350 1800
ELEMENTS OF PLANS 1-3


NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
1 GAUGE LOCATION AND NUMBER
N
SNAKE RIVER
EL-12
EL-12
EL-8
EL-22
EL-22
ENTRANCE CLOSED FOR PLAN 5
PLAN 4
PLAN 5
0
10
20
0
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
SCALES IN FEET
MODEL 0 5 10 15 20
PROTOTYPE 0 450 900 1350 1800
ELEMENTS OF PLANS 4-5

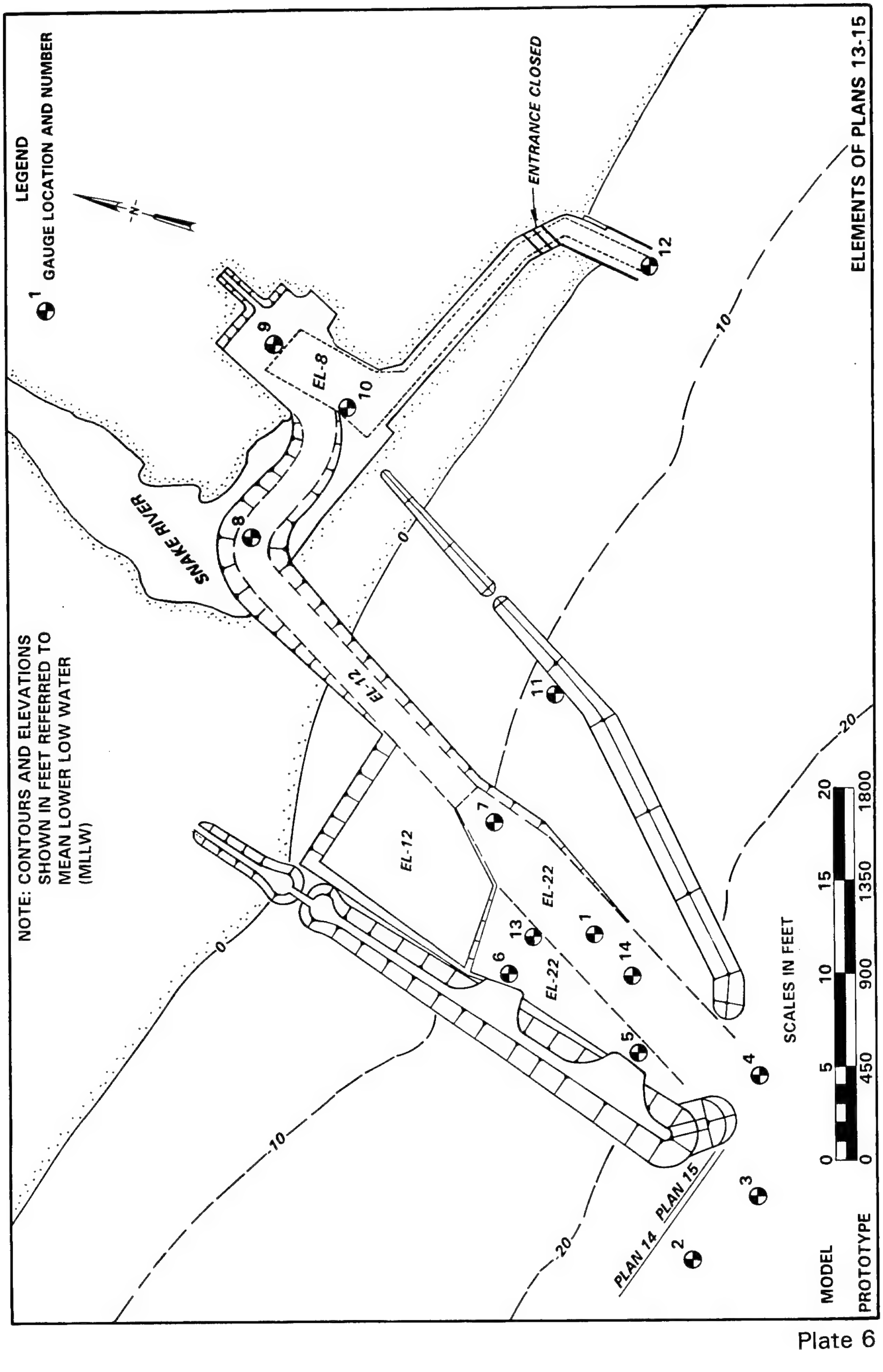


NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
GAUGE LOCATION AND NUMBER
N
SNAKE RIVER
ENTRANCE CLOSED
EL-8
EL-12
EL-12
EL-22
EL-22
0
0
10
10
20
PLAN 6
PLANS 7-8
PLAN 8
PLANS 6-7
1
2
3
4
5
6
7
8
9
10
11
12
13
14
SCALES IN FEET
MODEL
PROTOTYPE
0
5
10
15
20
0
450
900
1350
1800
ELEMENTS OF PLANS 6-8

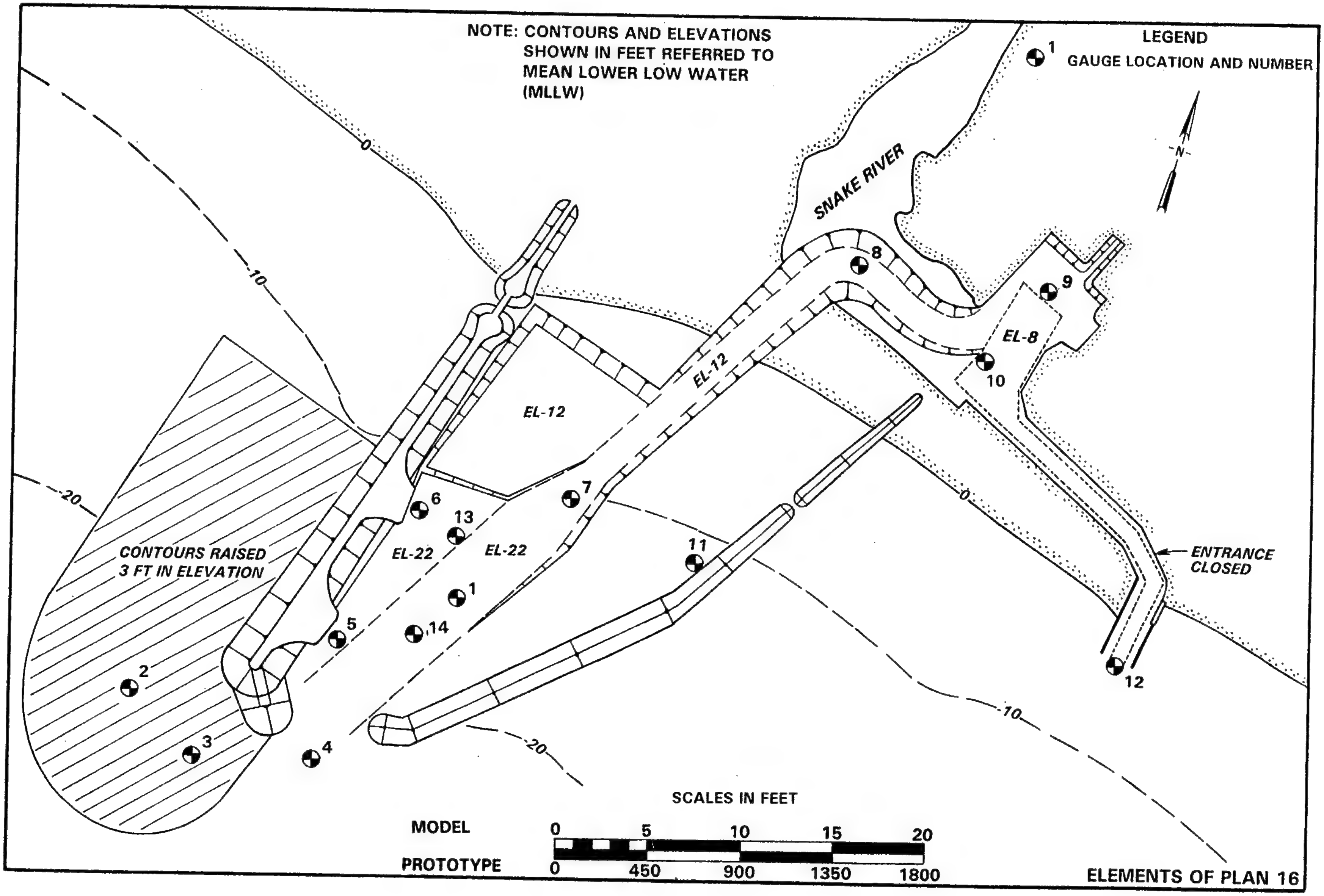


NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
GAUGE LOCATION AND NUMBER
N
ENTRANCE CLOSED
EL-8
EL-12
EL-22
PLAN 12
PLANS 9-11
PLAN 11
PLAN 10
SCALES IN FEET
MODEL
PROTOTYPE
ELEMENTS OF PLANS 9-12

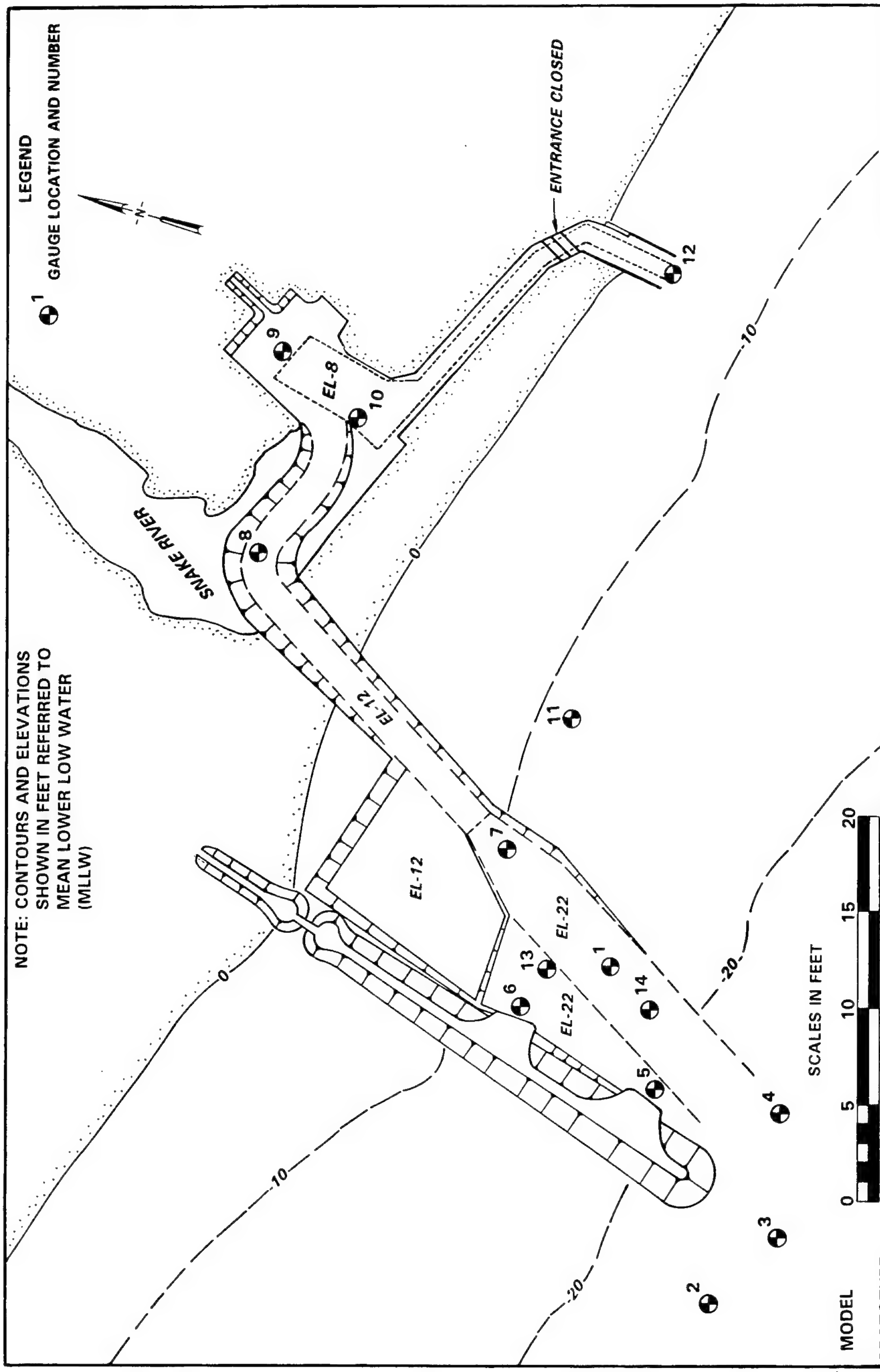
Plate 5



NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
GAUGE LOCATION AND NUMBER
N
ENTRANCE CLOSED
SNAKE RIVER
EL-8
EL-12
EL-22
PLAN 14
PLAN 15
SCALES IN FEET
MODEL
PROTOTYPE
0
5
10
15
20
0
450
900
1350
1800
ELEMENTS OF PLANS 13-15

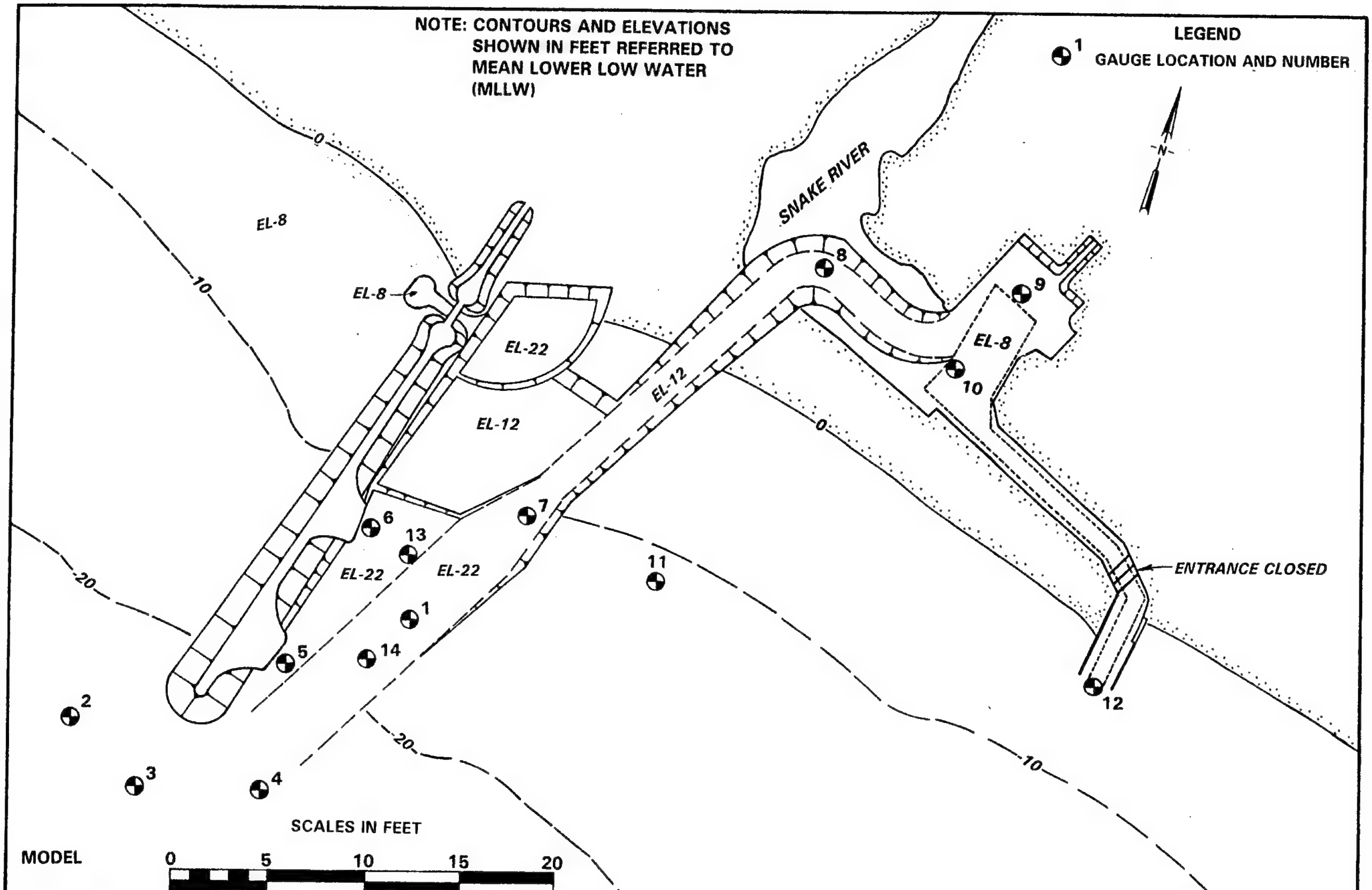


ELEMENTS OF PLAN 16

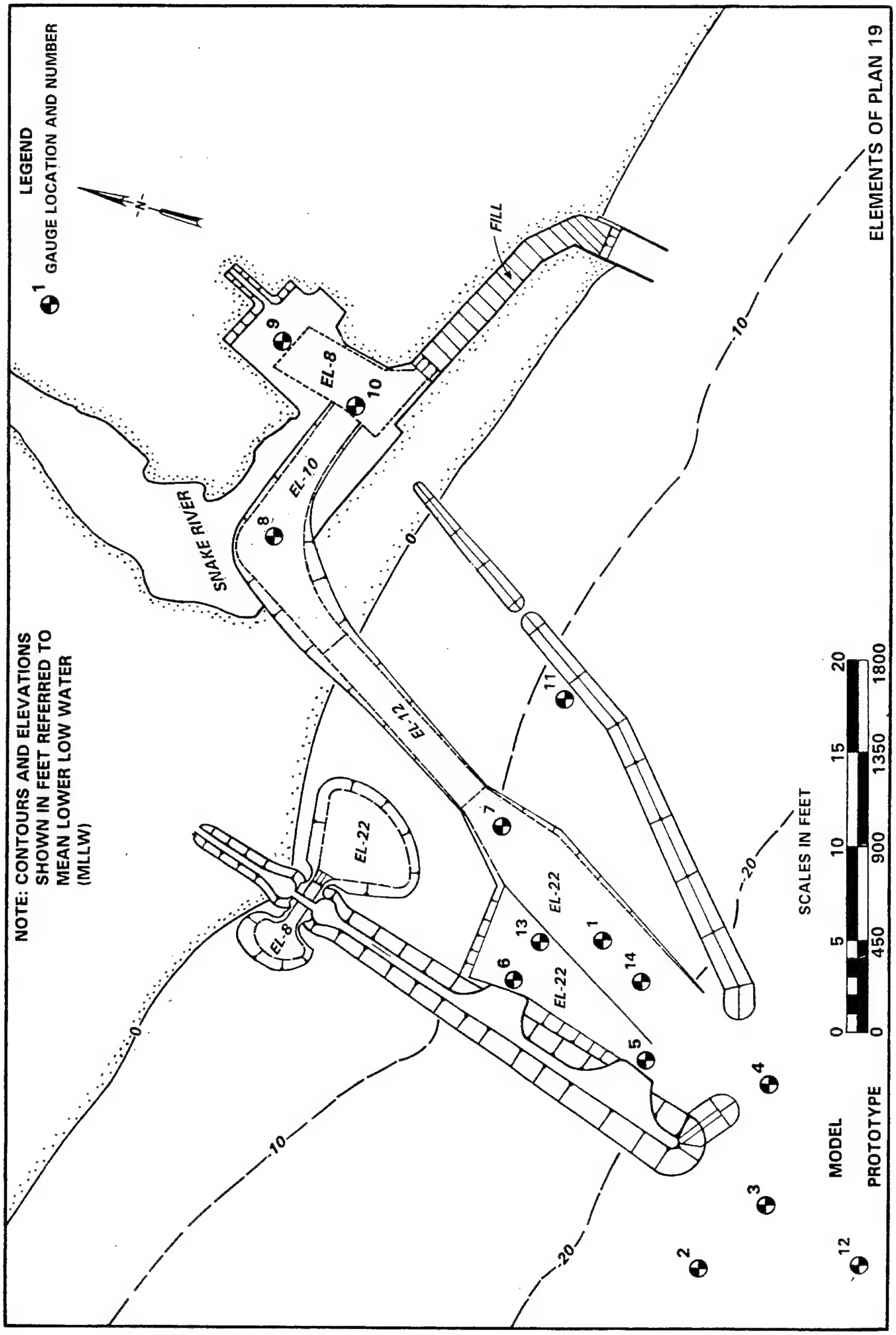


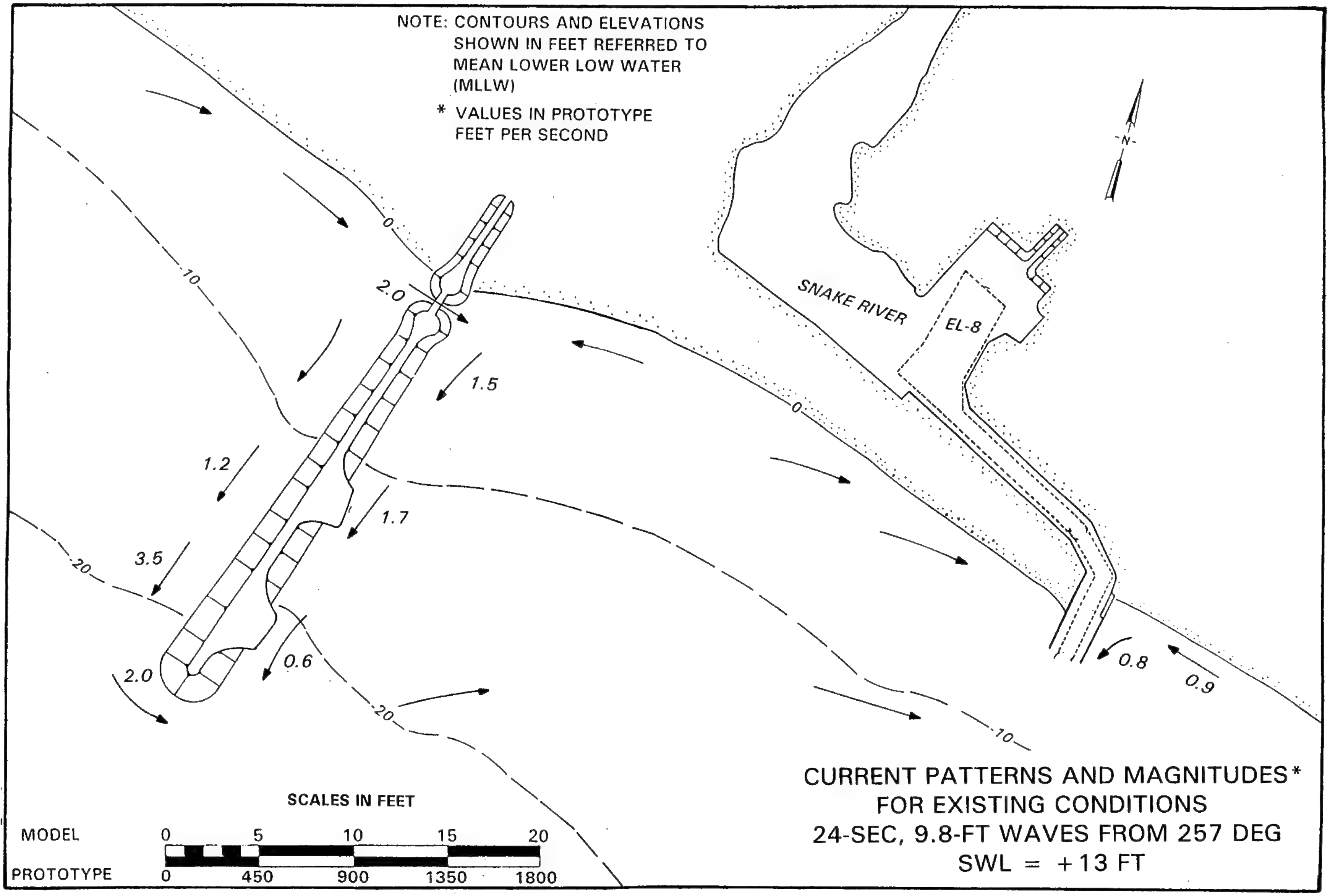
ELEMENTS OF PLAN 17

Plate 8

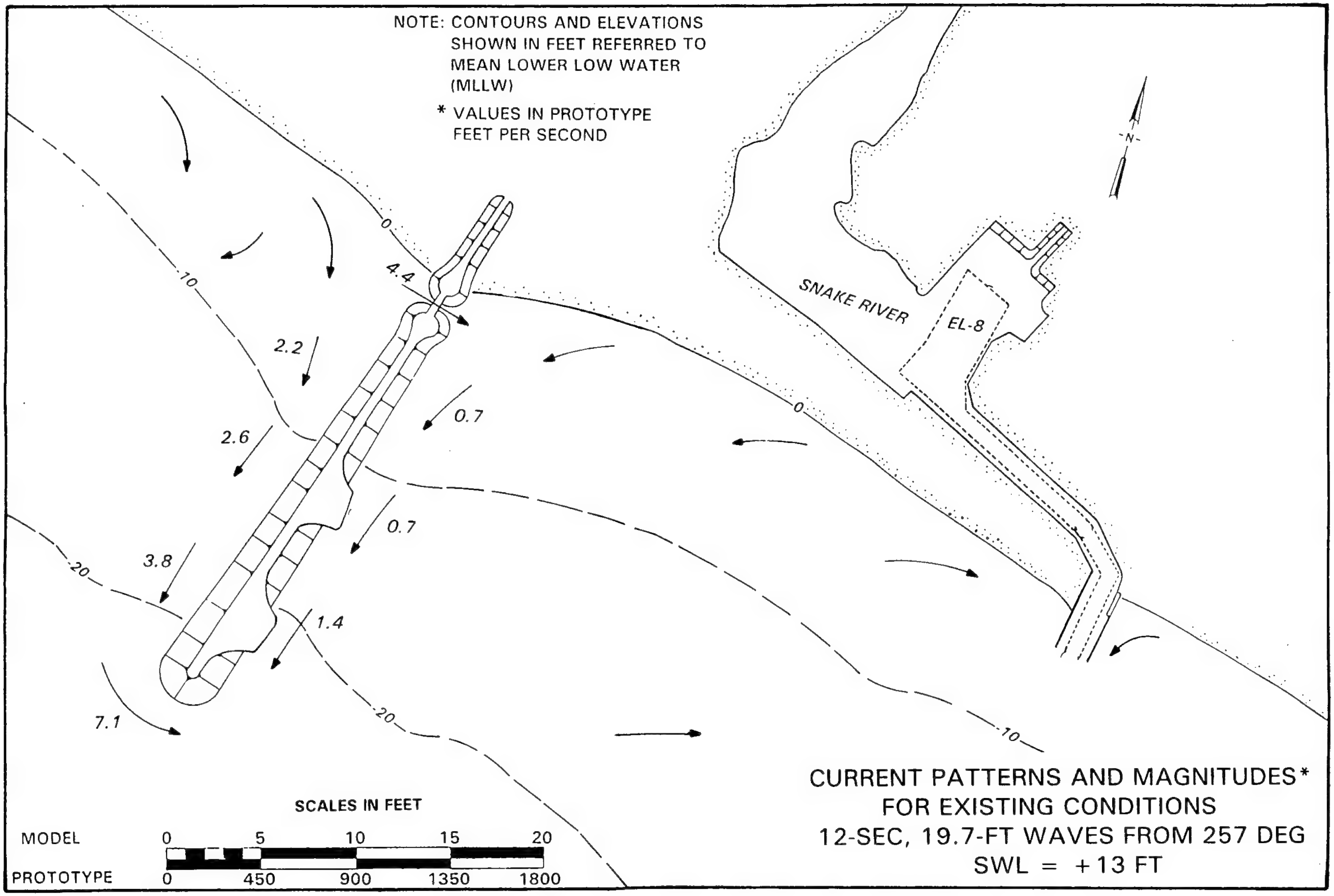


ELEMENTS OF PLAN 18

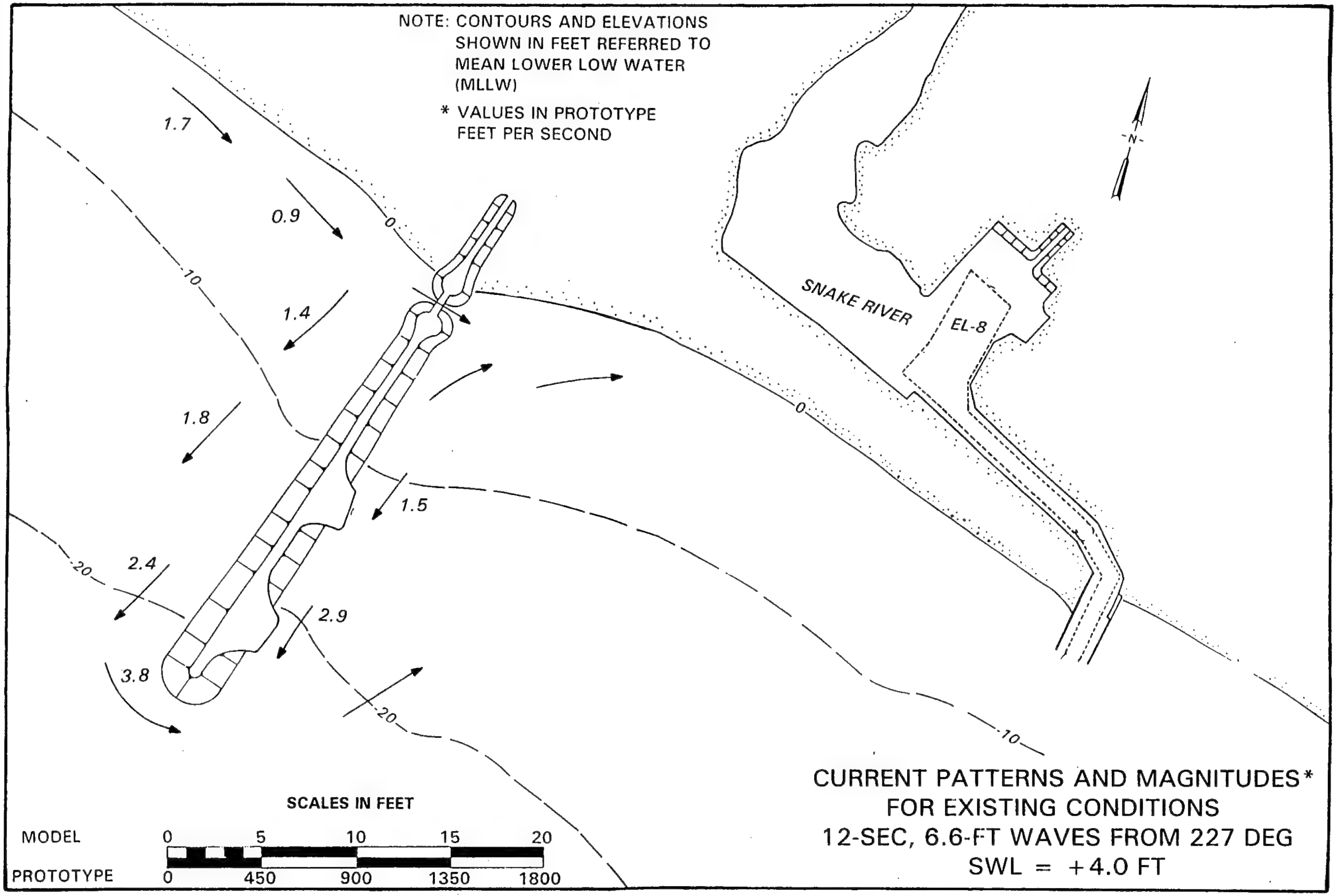

NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
GAUGE LOCATION AND NUMBER
N
FILL
SNAKE RIVER
EL-8
EL-10
EL-12
EL-22
0
10
20
SCALES IN FEET
MODEL
PROTOTYPE
0 5 10 15 20
0 450 900 1350 1800
ELEMENTS OF PLAN 19



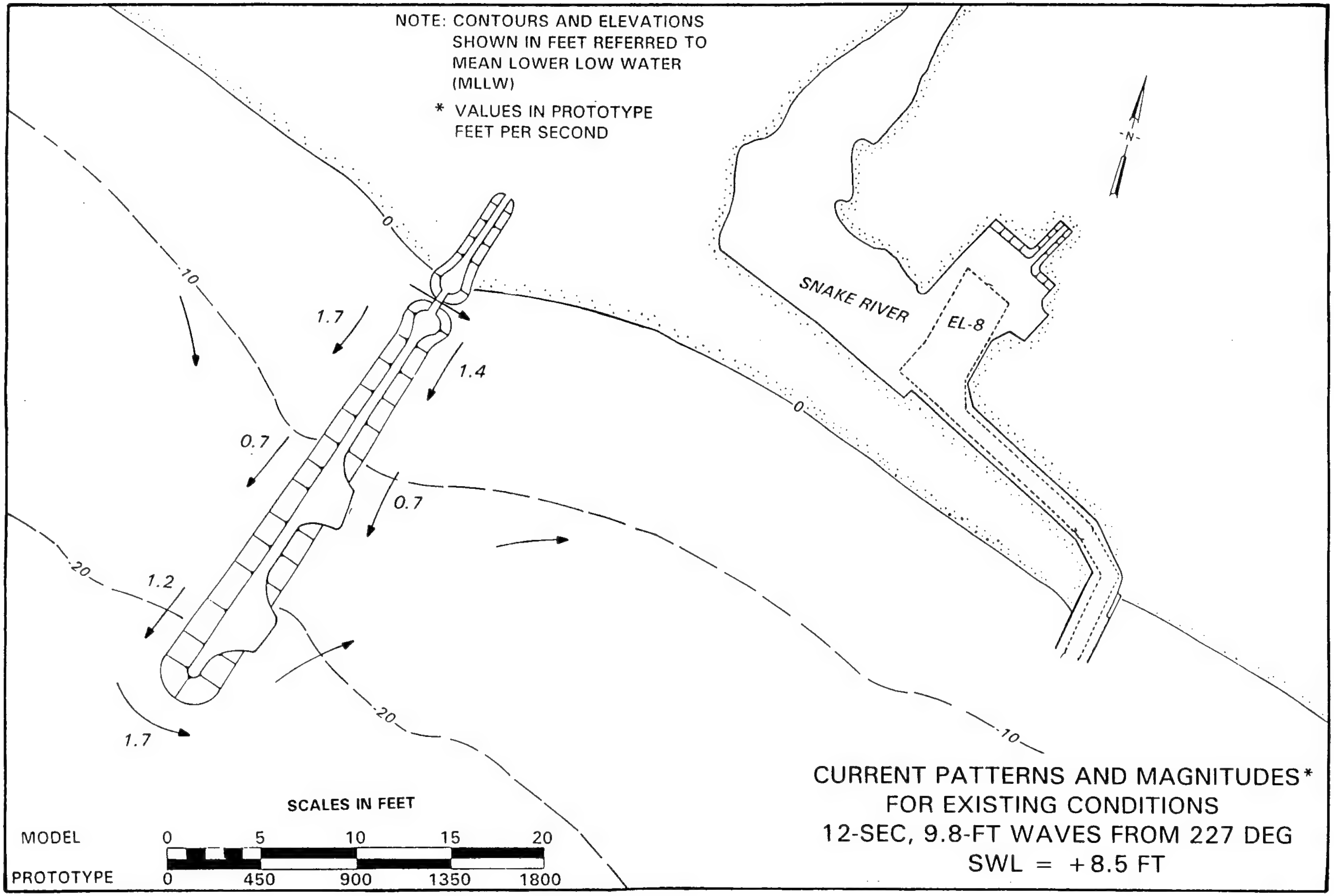
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
24-SEC, 9.8-FT WAVES FROM 257 DEG
SWL = +13 FT



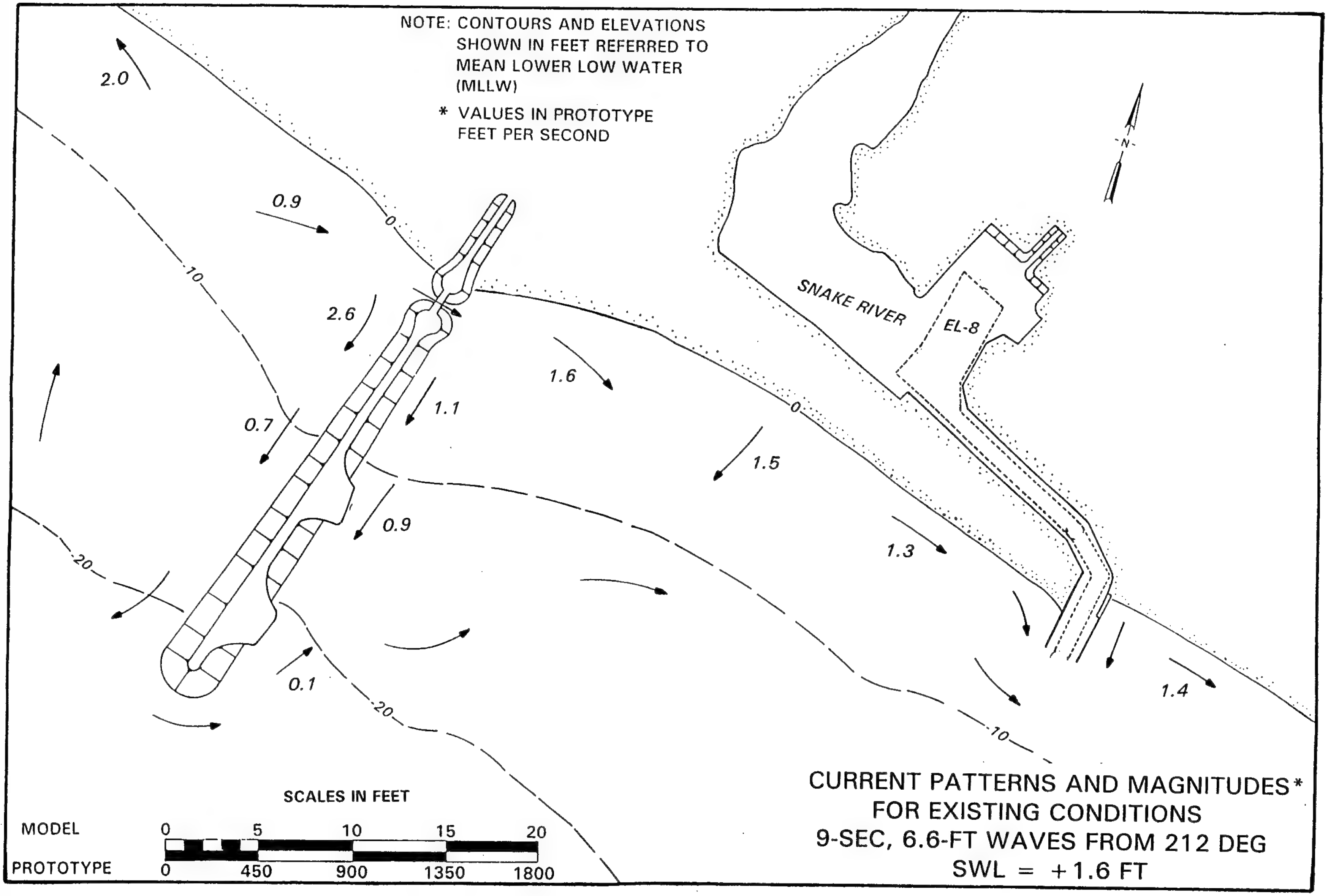
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
12-SEC, 19.7-FT WAVES FROM 257 DEG
SWL = +13 FT



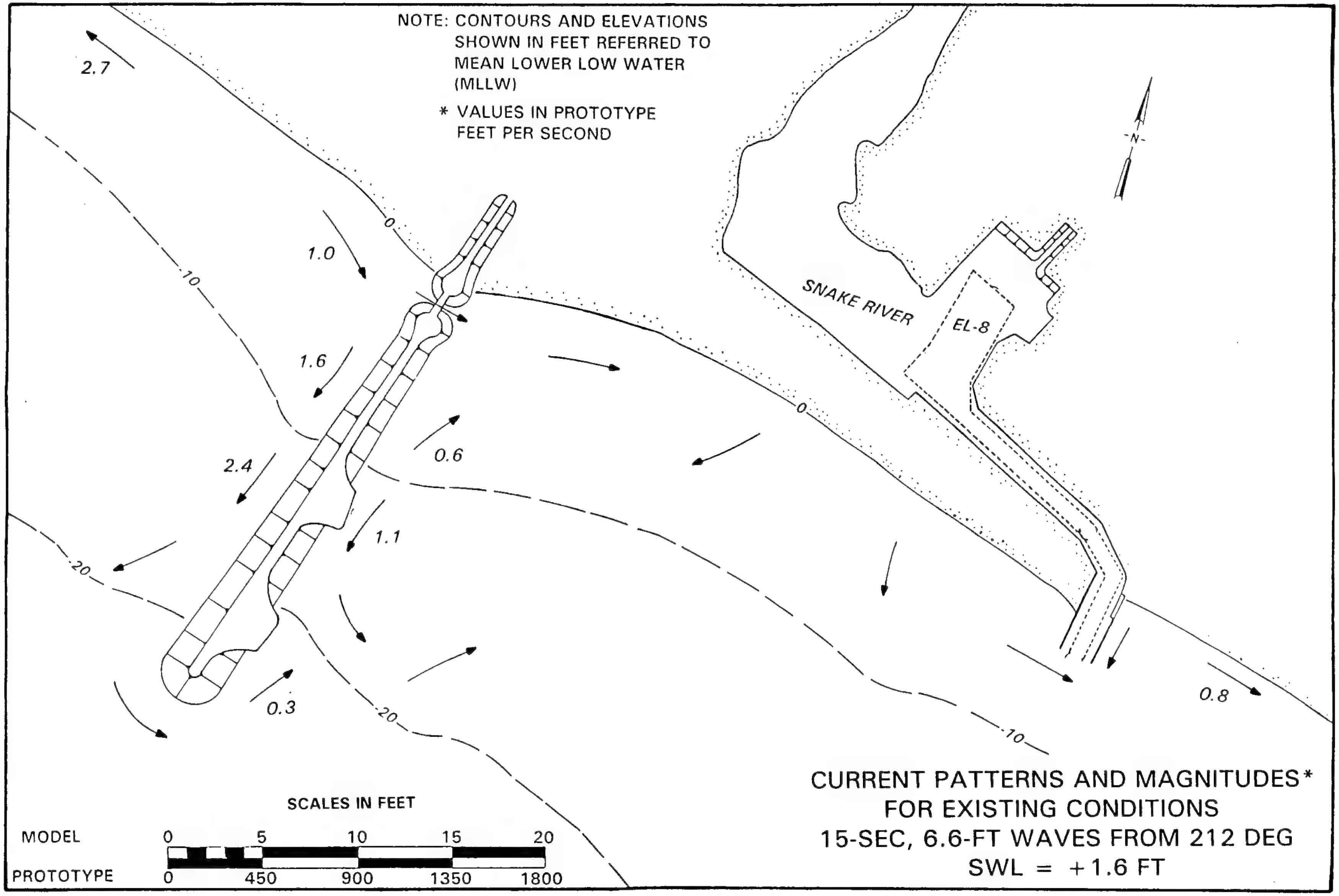
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
12-SEC, 6.6-FT WAVES FROM 227 DEG
SWL = +4.0 FT



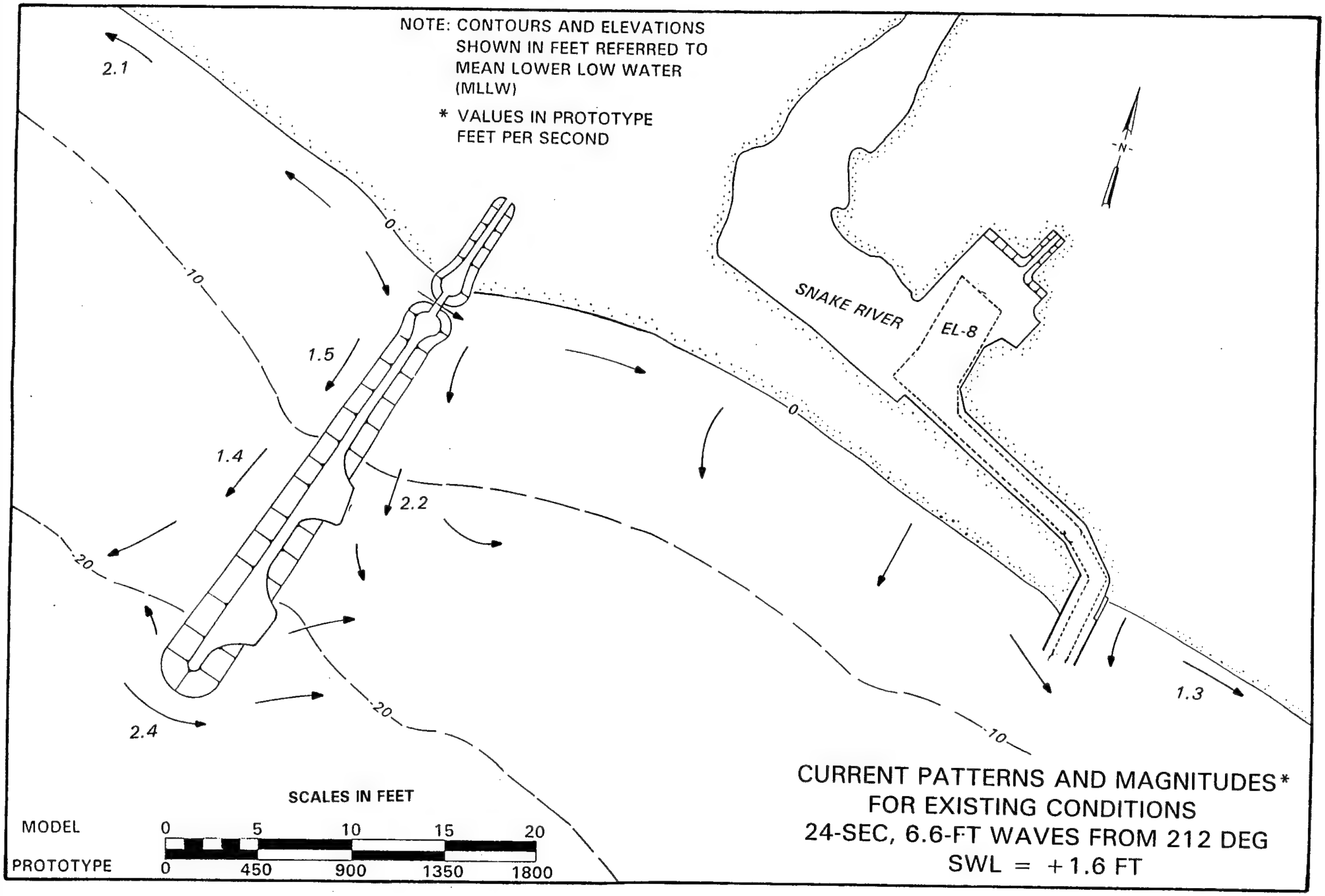
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
12-SEC, 9.8-FT WAVES FROM 227 DEG
SWL = +8.5 FT



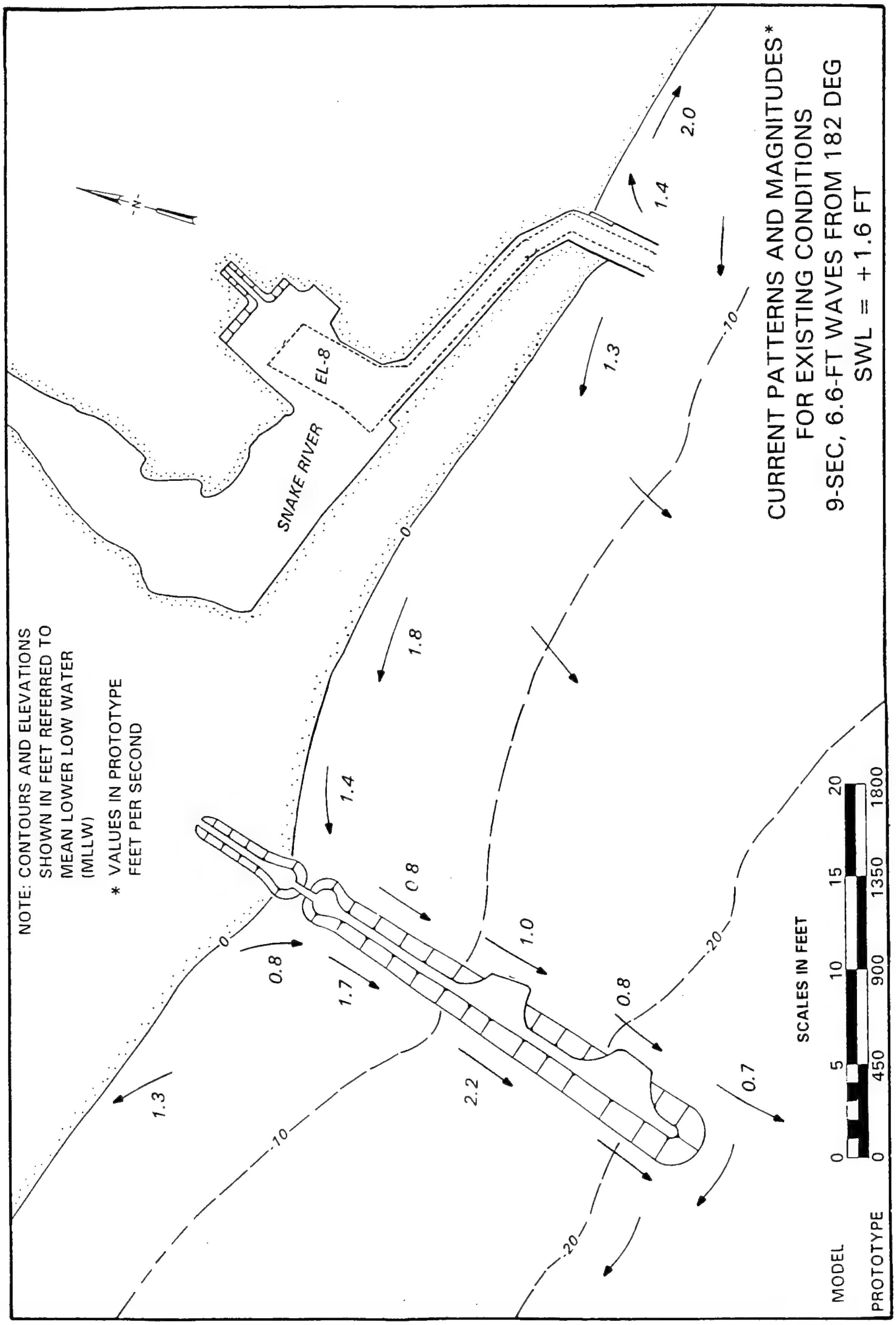
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
9-SEC, 6.6-FT WAVES FROM 212 DEG
SWL = +1.6 FT



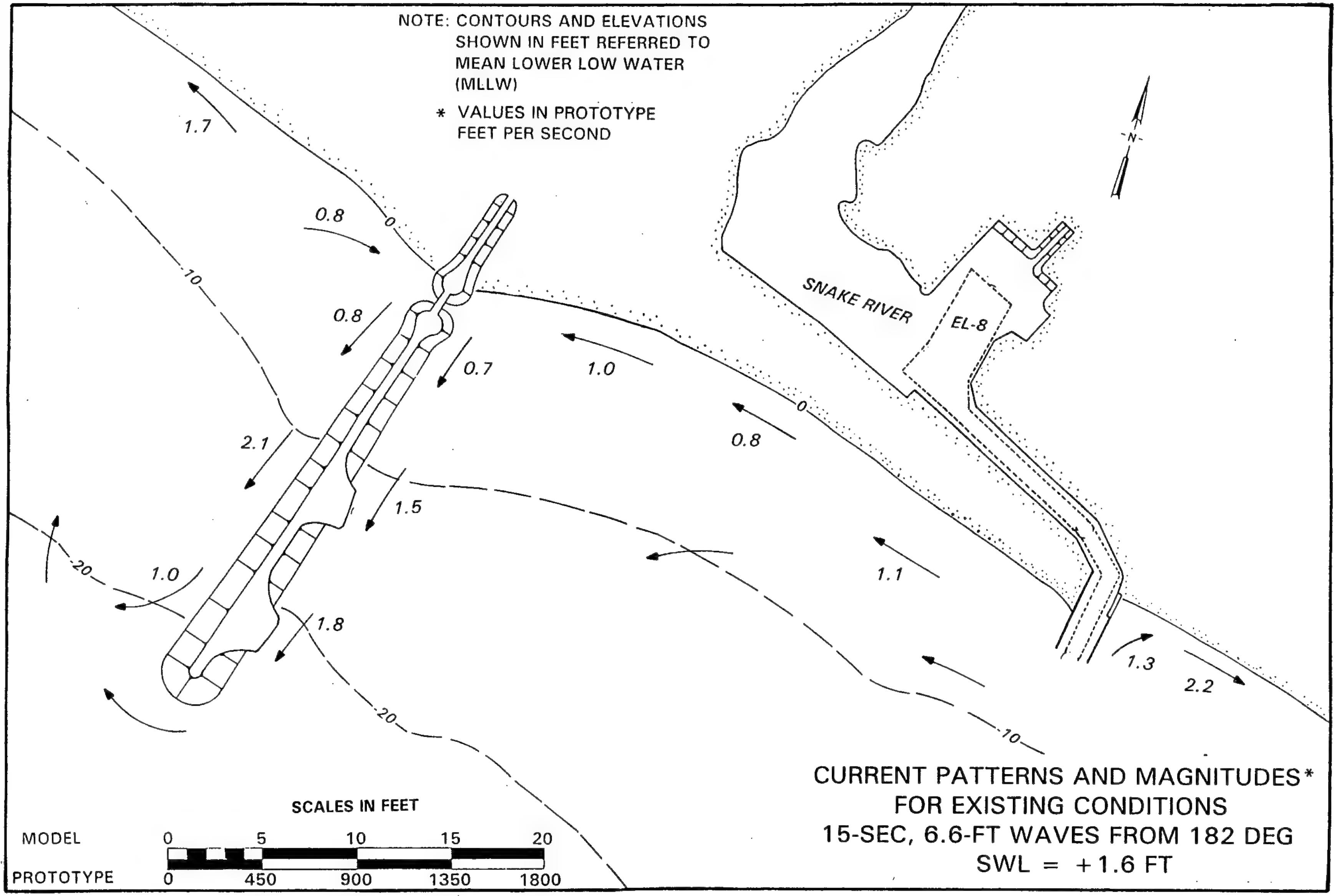
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
15-SEC, 6.6-FT WAVES FROM 212 DEG
SWL = +1.6 FT



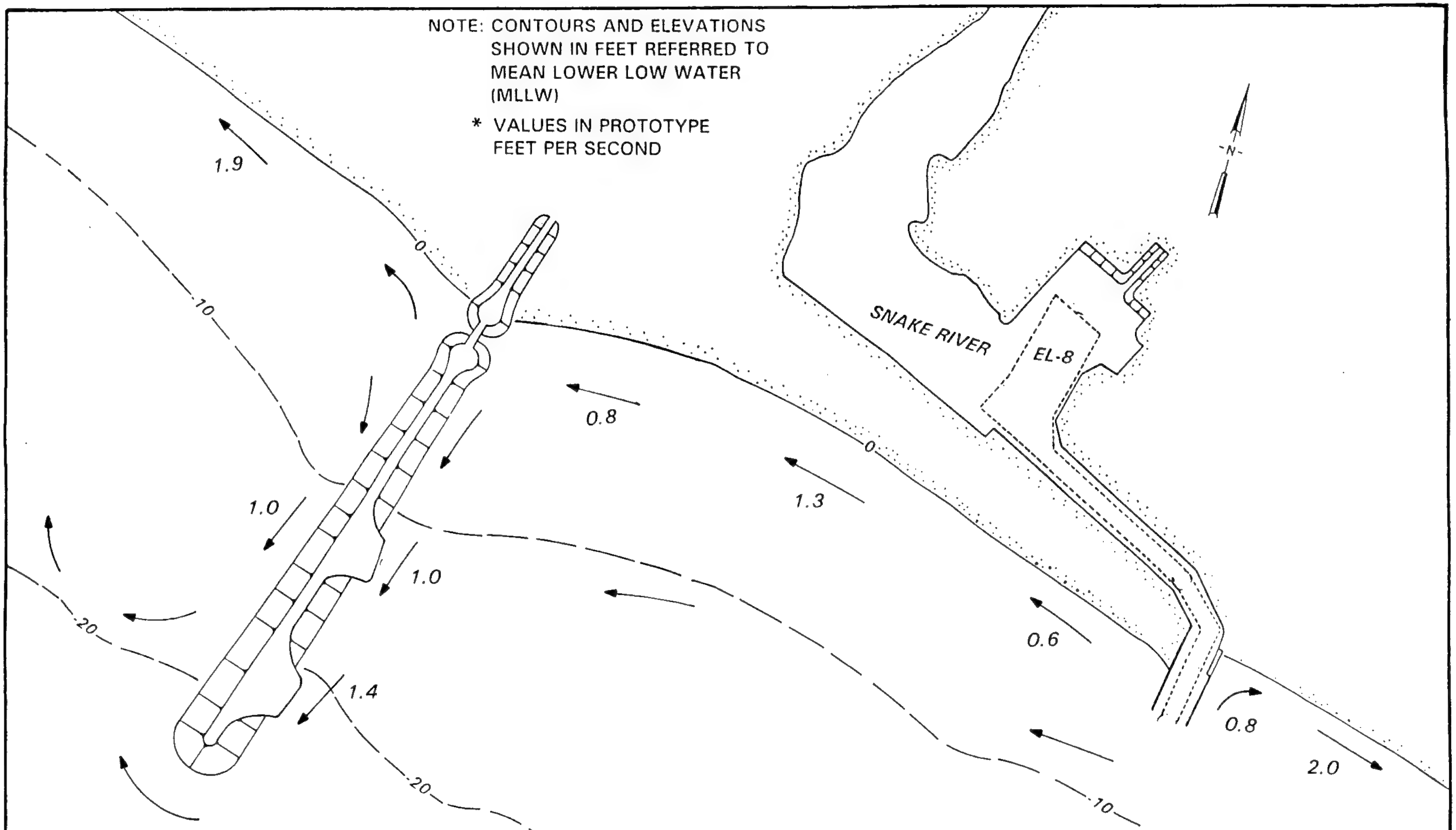
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
24-SEC, 6.6-FT WAVES FROM 212 DEG
SWL = +1.6 FT



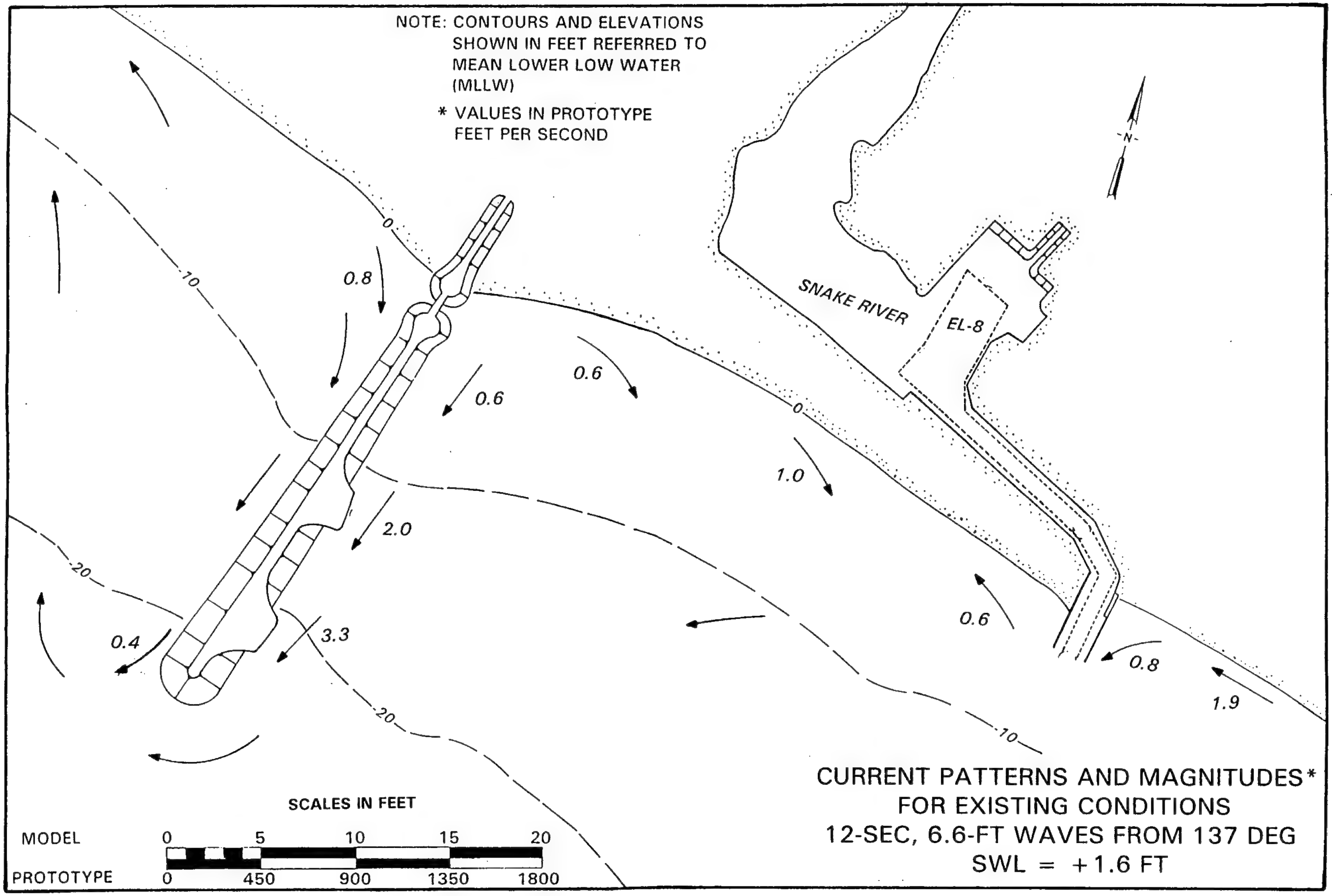
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
9-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT



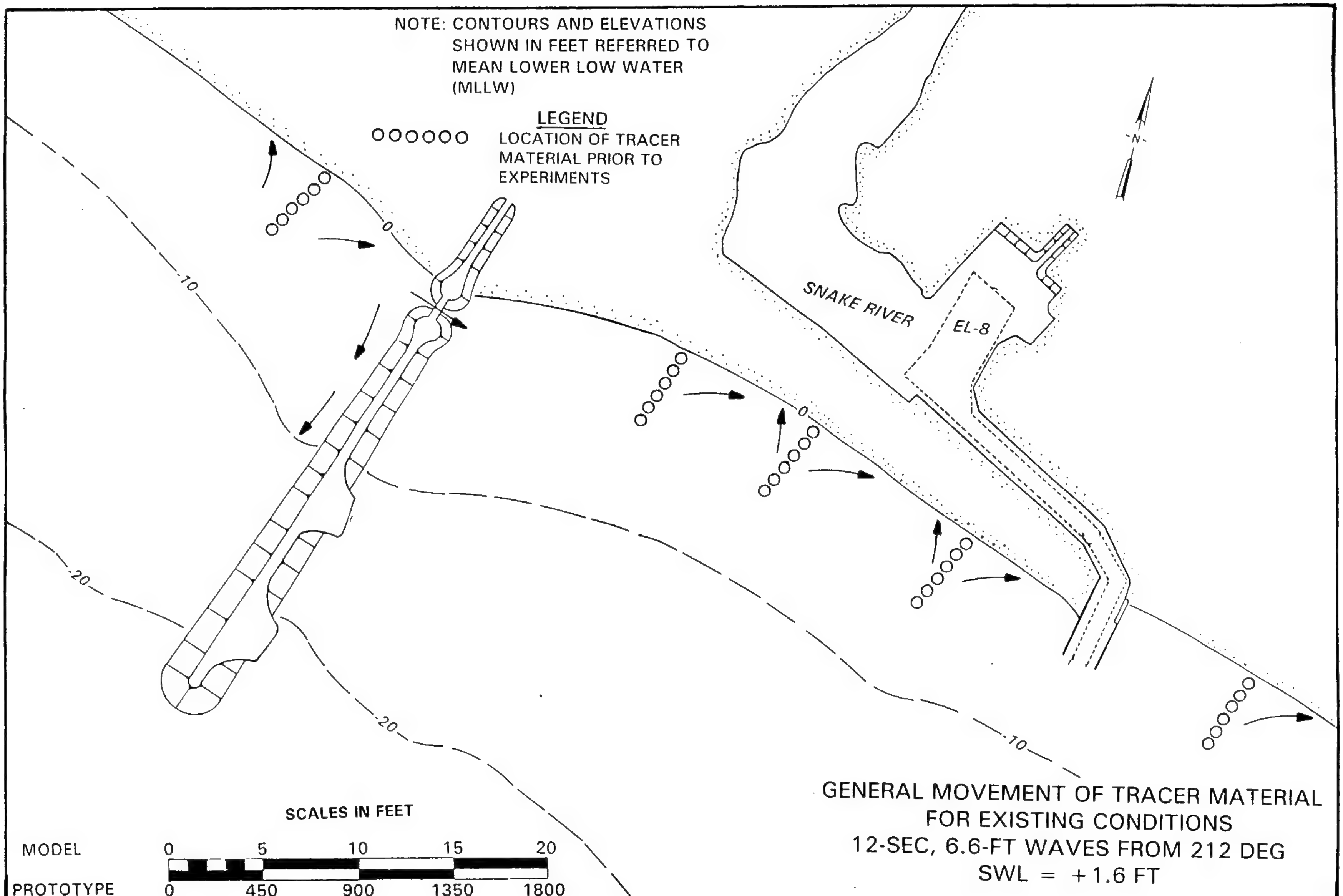
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
15-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT



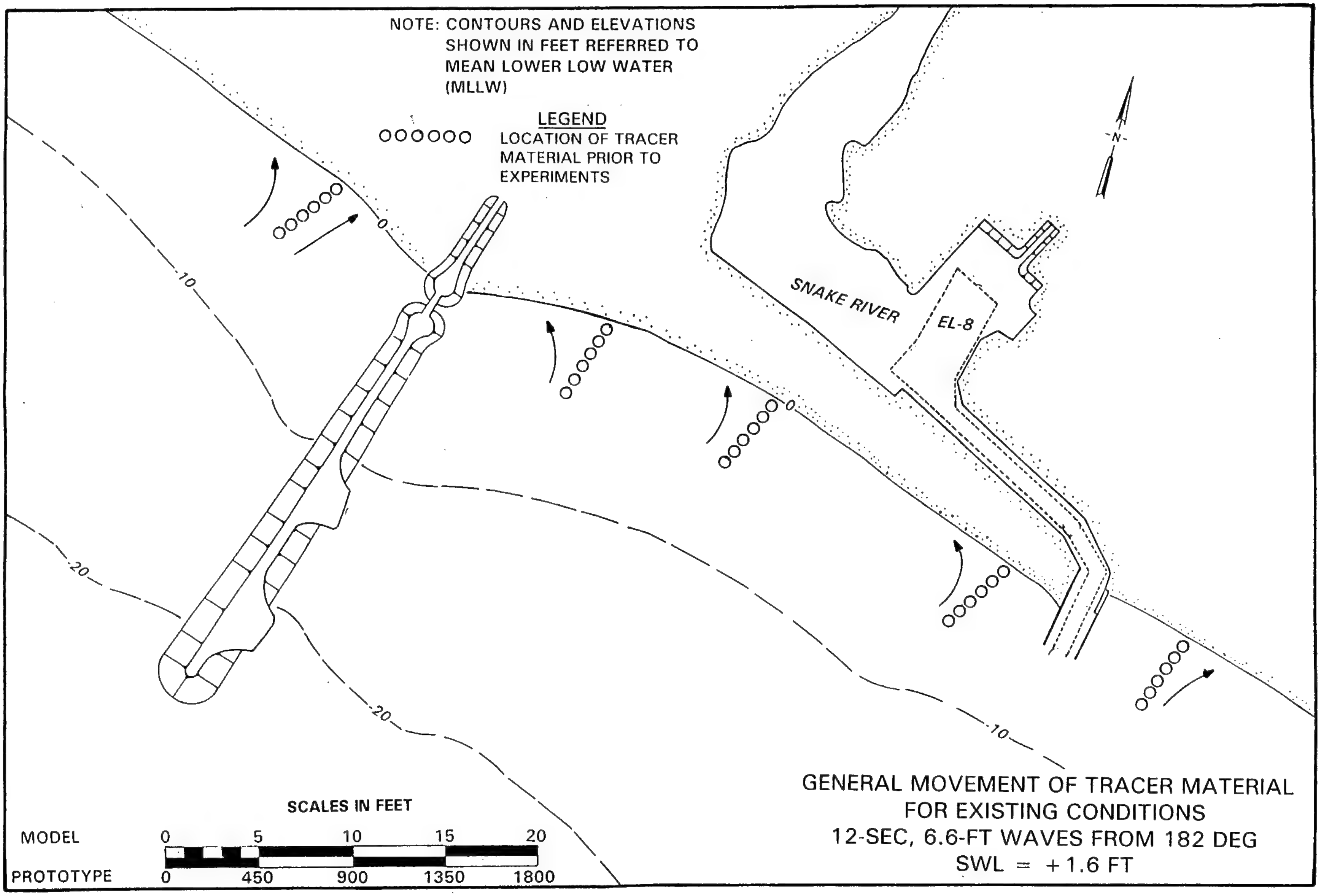
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
24-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT



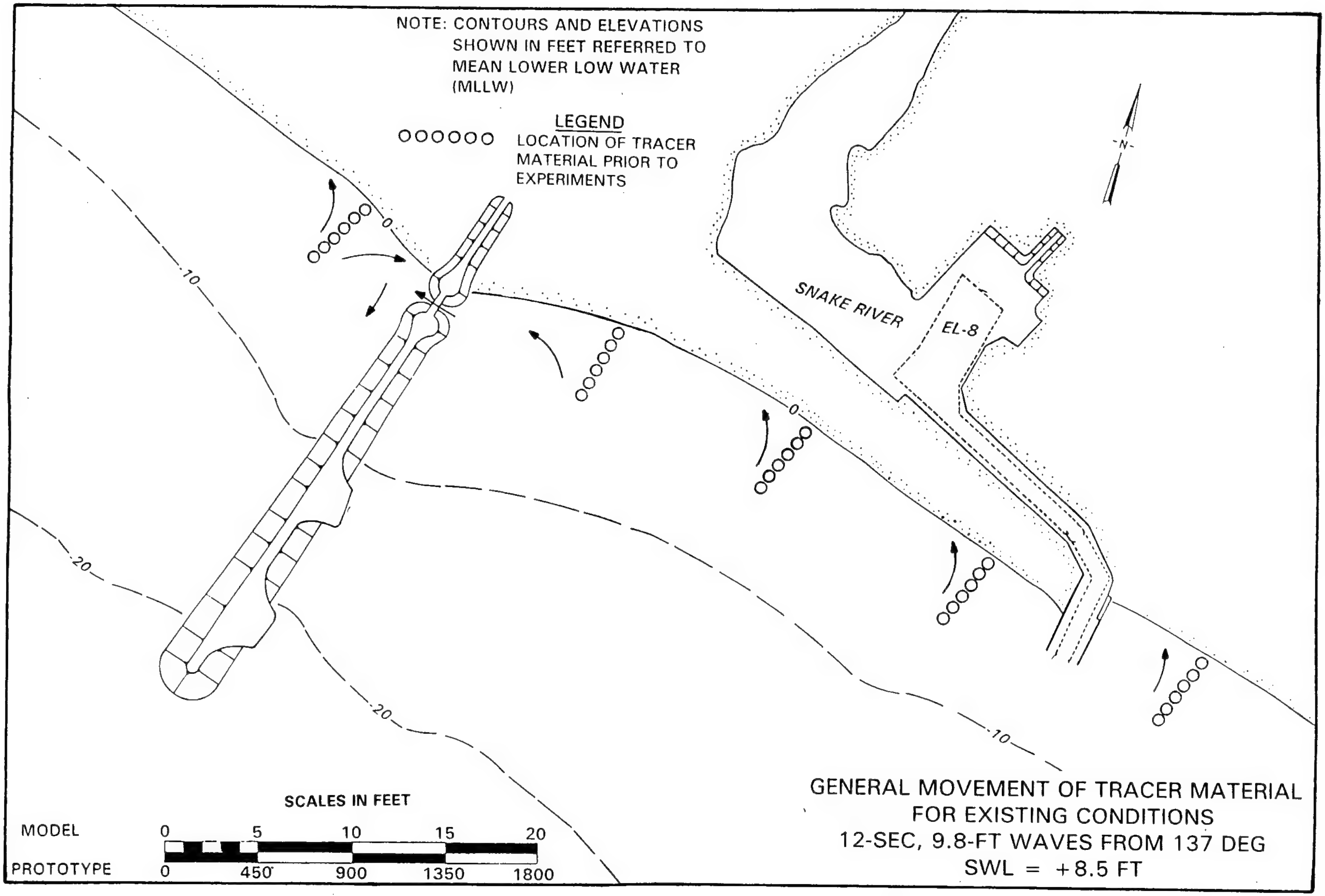
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
12-SEC, 6.6-FT WAVES FROM 137 DEG
SWL = +1.6 FT



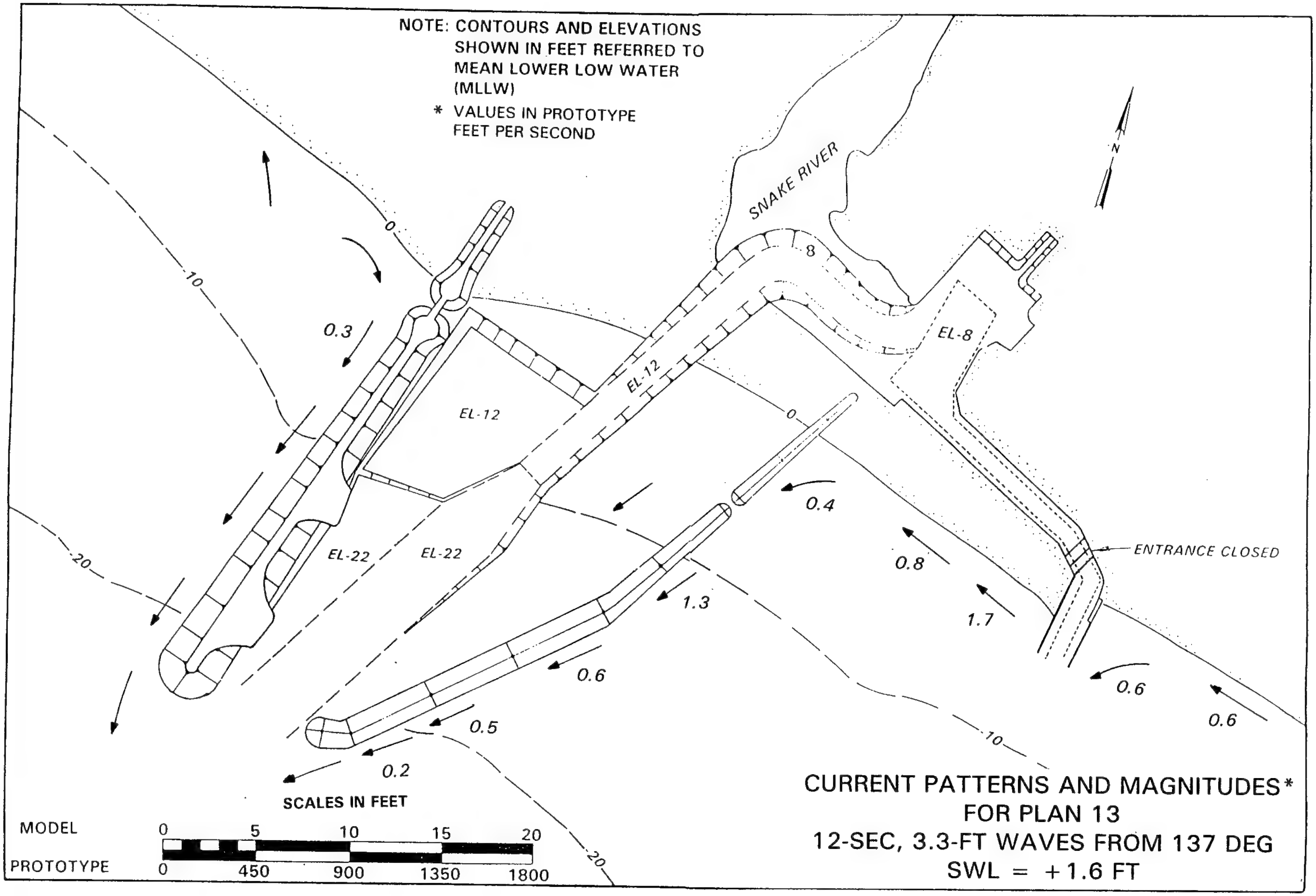
GENERAL MOVEMENT OF TRACER MATERIAL
FOR EXISTING CONDITIONS
12-SEC, 6.6-FT WAVES FROM 212 DEG
SWL = +1.6 FT



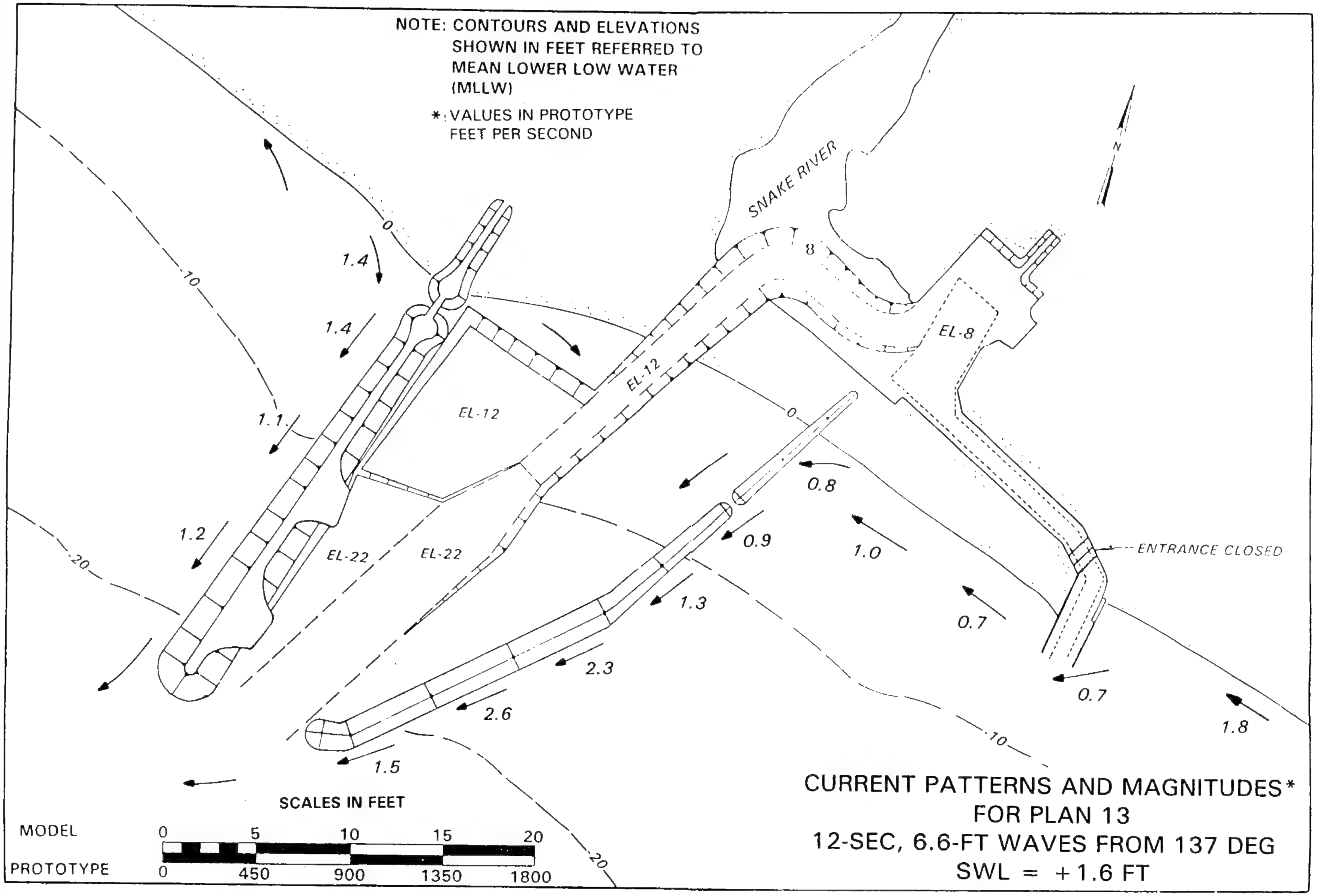
GENERAL MOVEMENT OF TRACER MATERIAL
FOR EXISTING CONDITIONS
12-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT

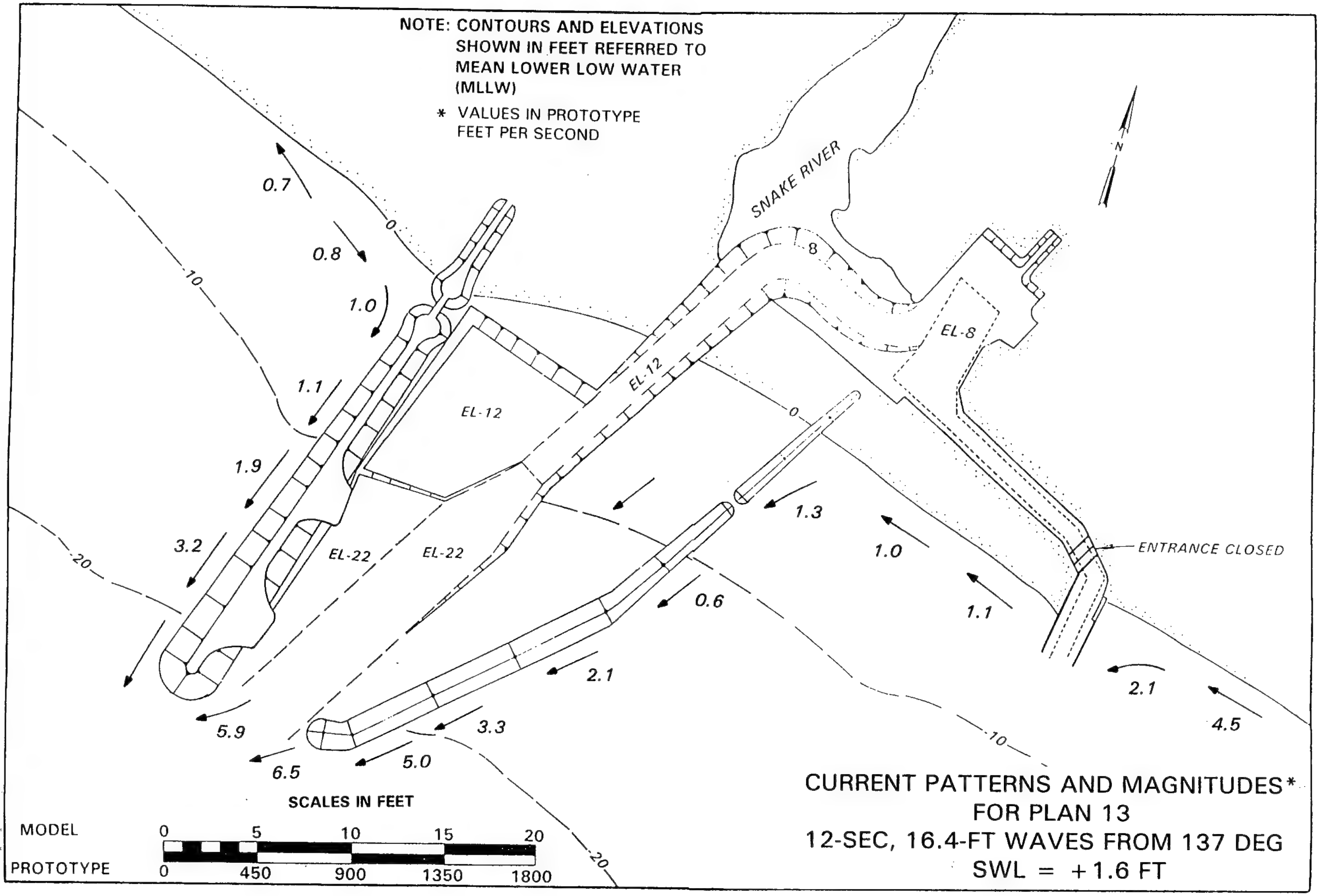


GENERAL MOVEMENT OF TRACER MATERIAL FOR EXISTING CONDITIONS
12-SEC, 9.8-FT WAVES FROM 137 DEG
SWL = +8.5 FT

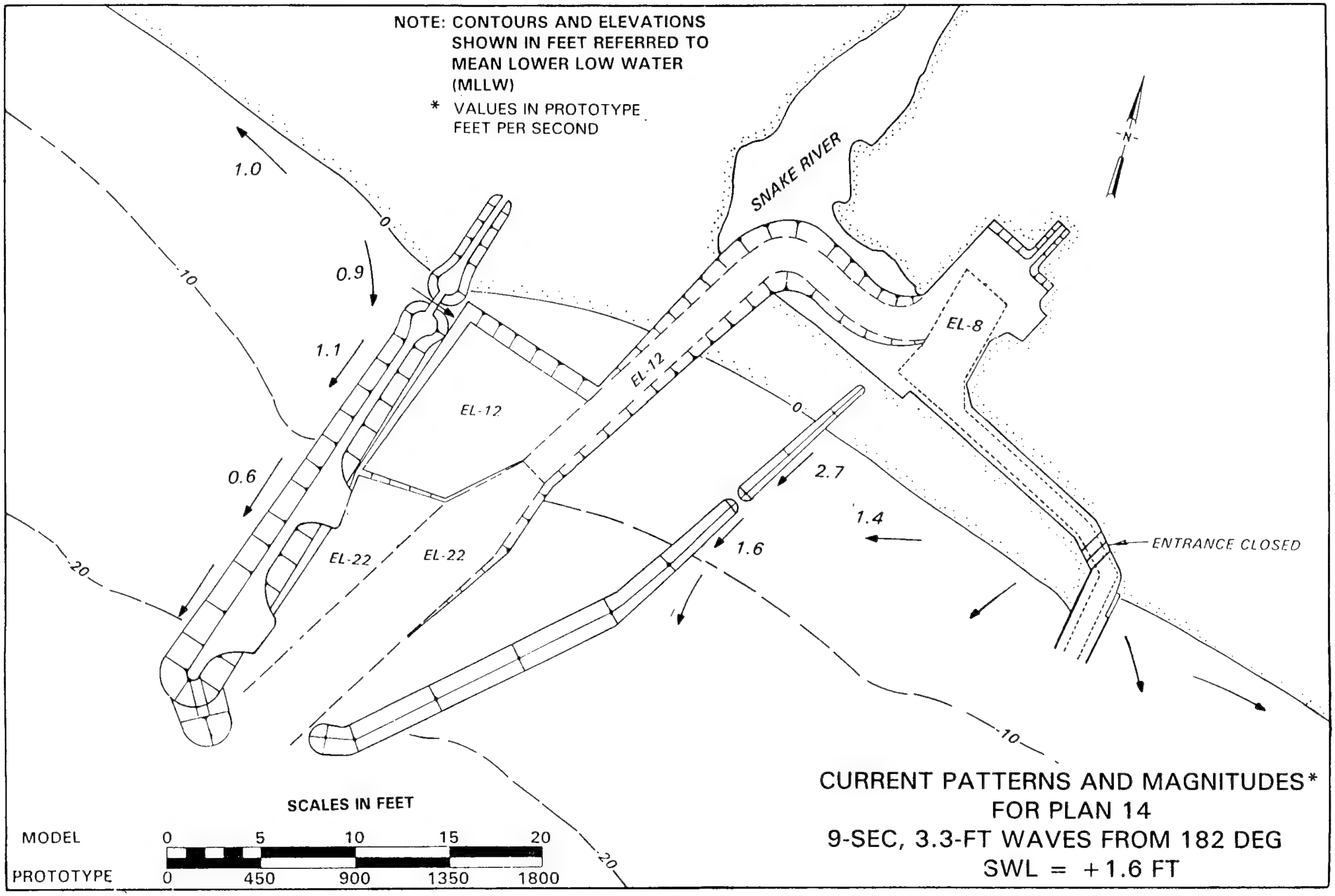


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 13
12-SEC, 3.3-FT WAVES FROM 137 DEG
SWL = +1.6 FT

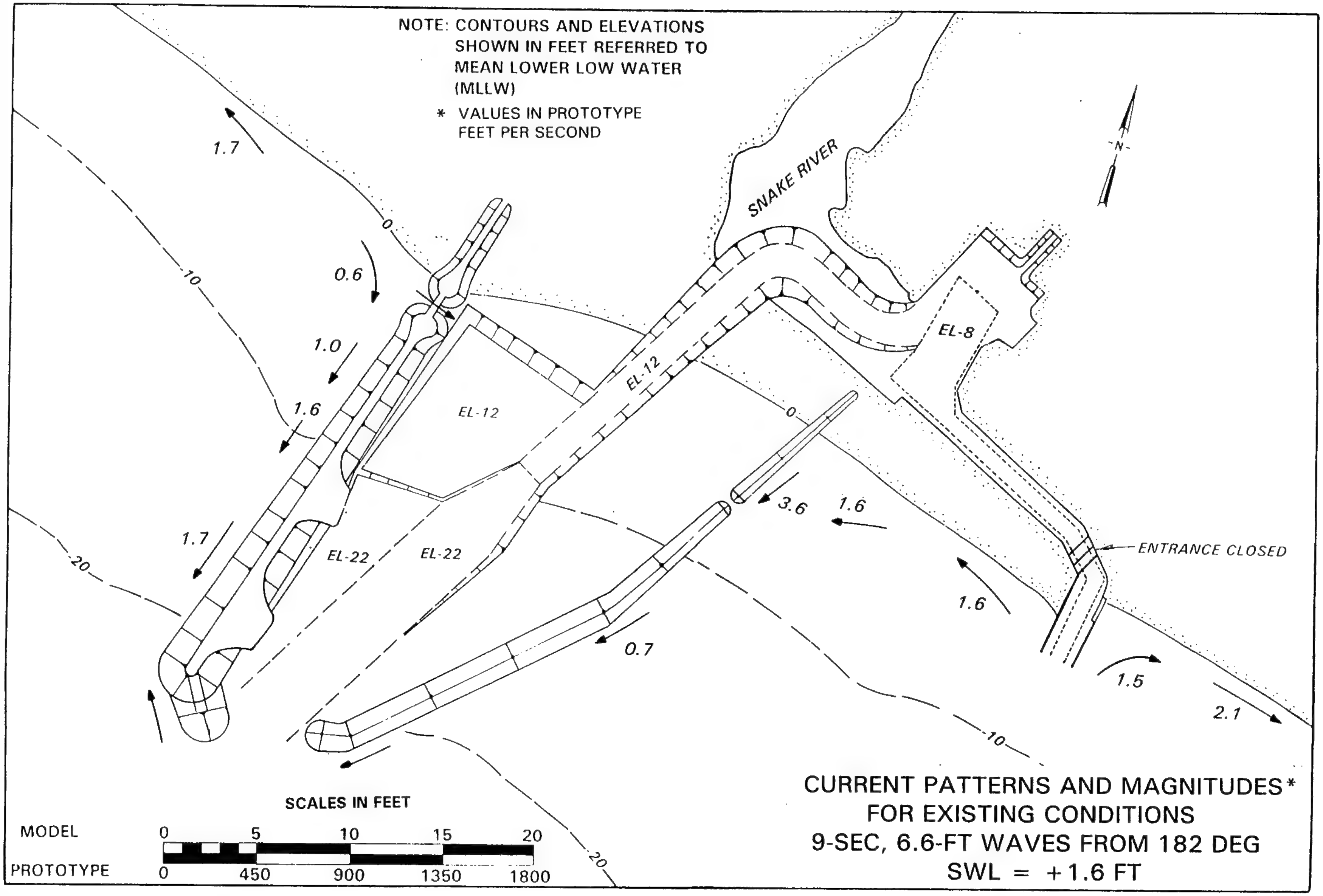

NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
*: VALUES IN PROTOTYPE FEET PER SECOND
SNAKE RIVER
N
ENTRANCE CLOSED
EL-8
EL-12
EL-12
EL-22
EL-22
0
0
8
10
10
20
20
1.4
1.4
1.1
1.2
0.8
0.9
1.0
0.7
0.7
1.3
2.3
2.6
1.5
1.8
SCALES IN FEET
MODEL
PROTOTYPE
0
5
10
15
20
0
450
900
1350
1800
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 13
12-SEC, 6.6-FT WAVES FROM 137 DEG
SWL = +1.6 FT



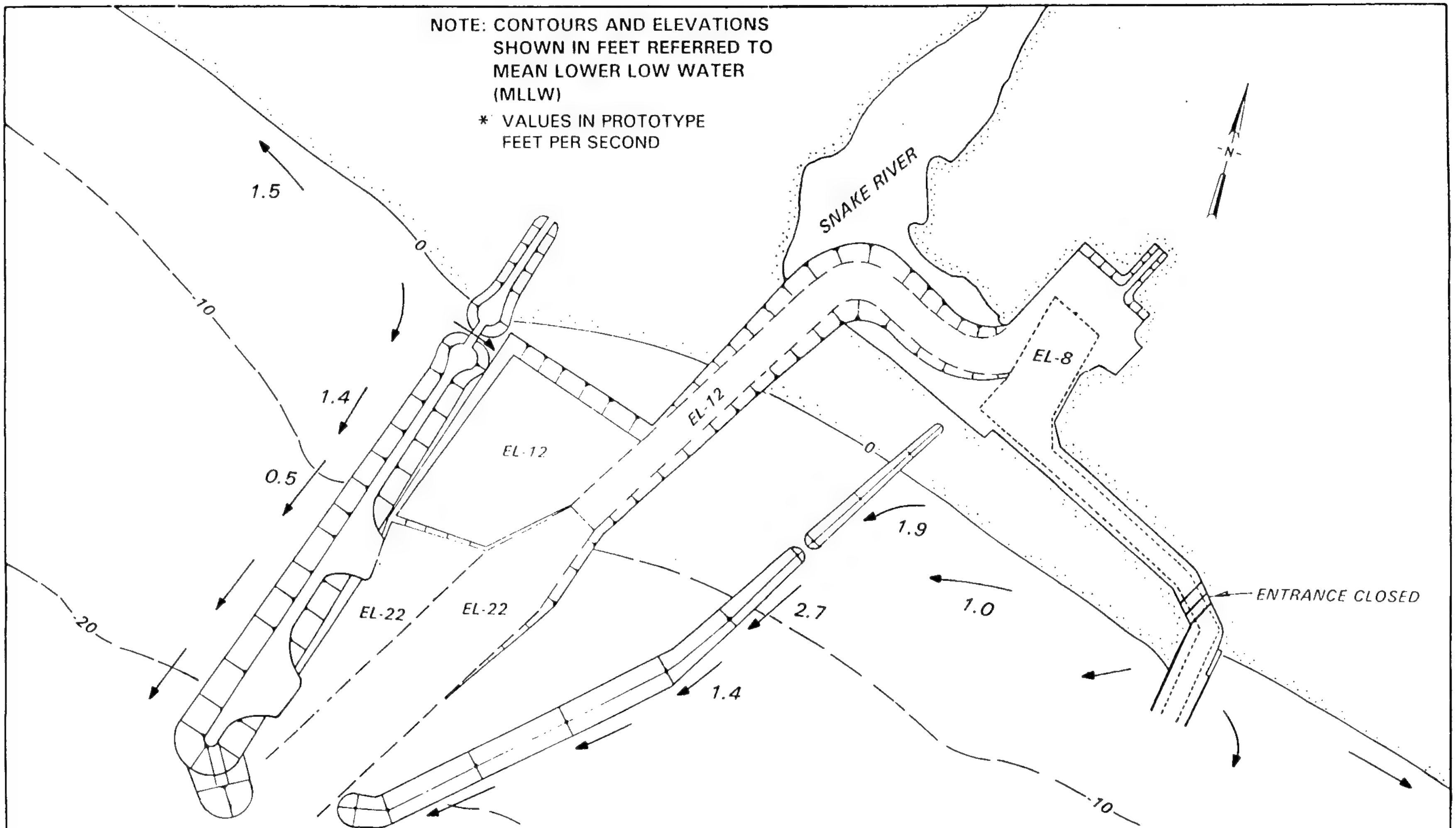
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 13
12-SEC, 16.4-FT WAVES FROM 137 DEG
SWL = +1.6 FT



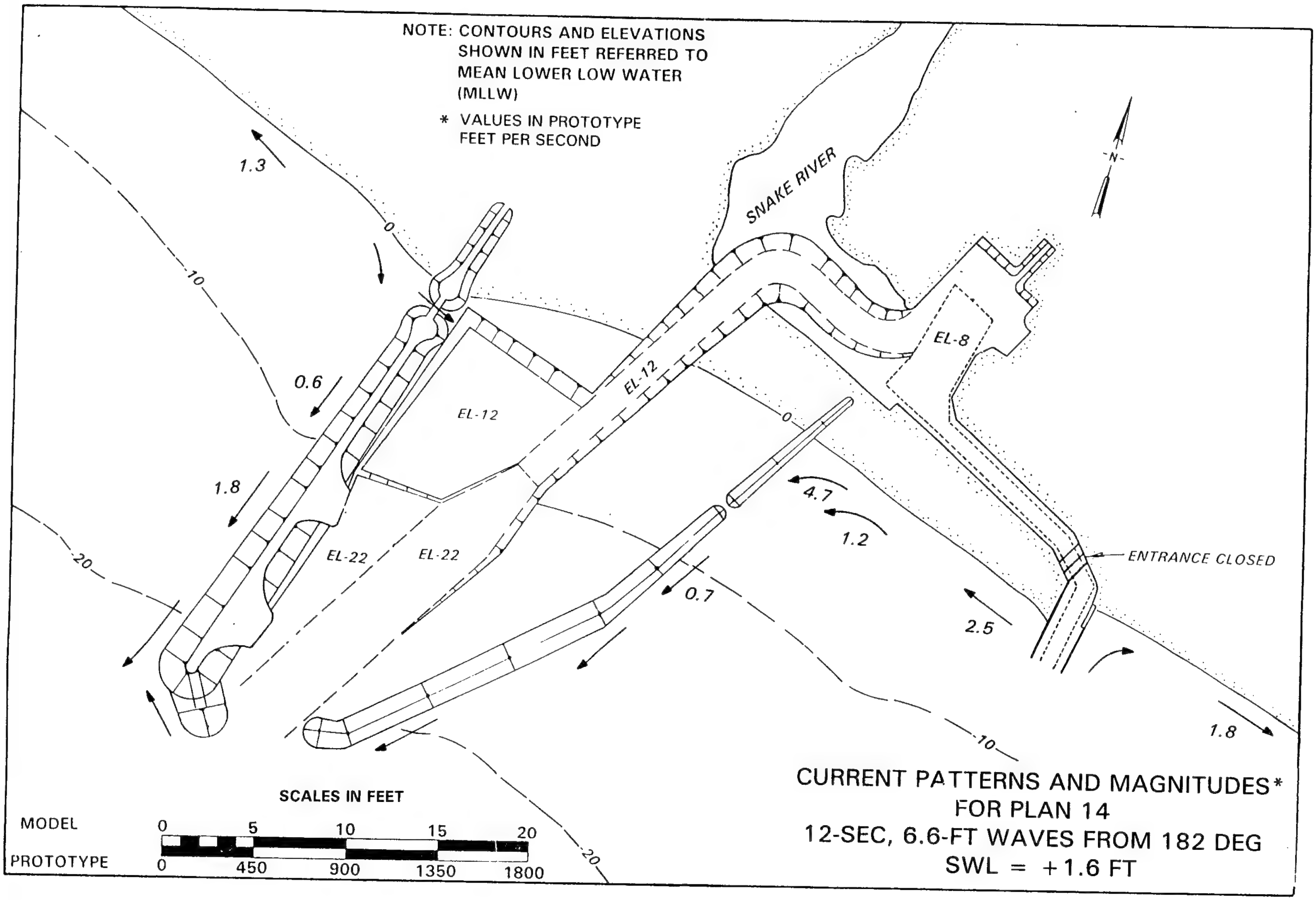
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
9-SEC, 3.3-FT WAVES FROM 182 DEG
SWL = +1.6 FT



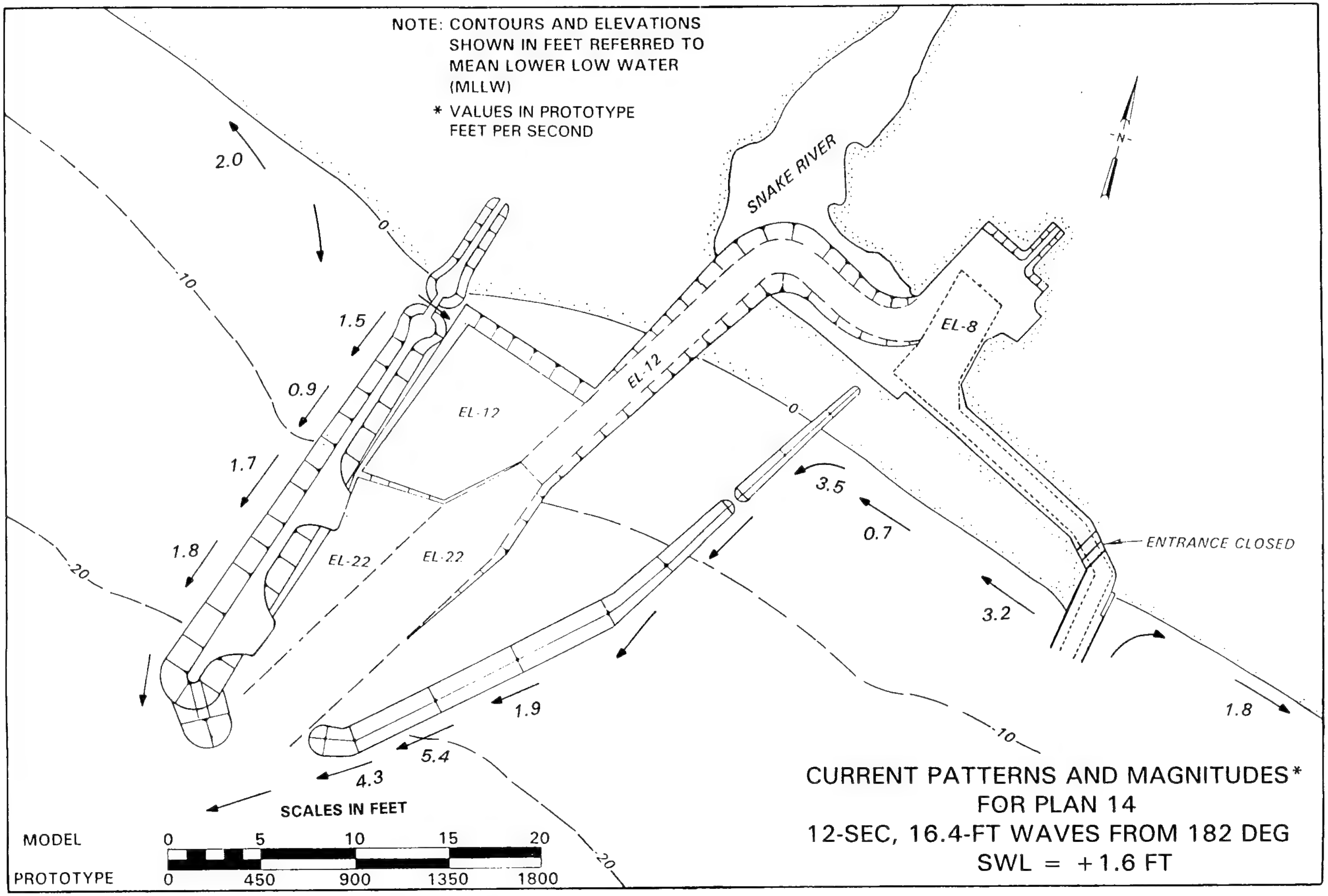
CURRENT PATTERNS AND MAGNITUDES*
FOR EXISTING CONDITIONS
9-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT



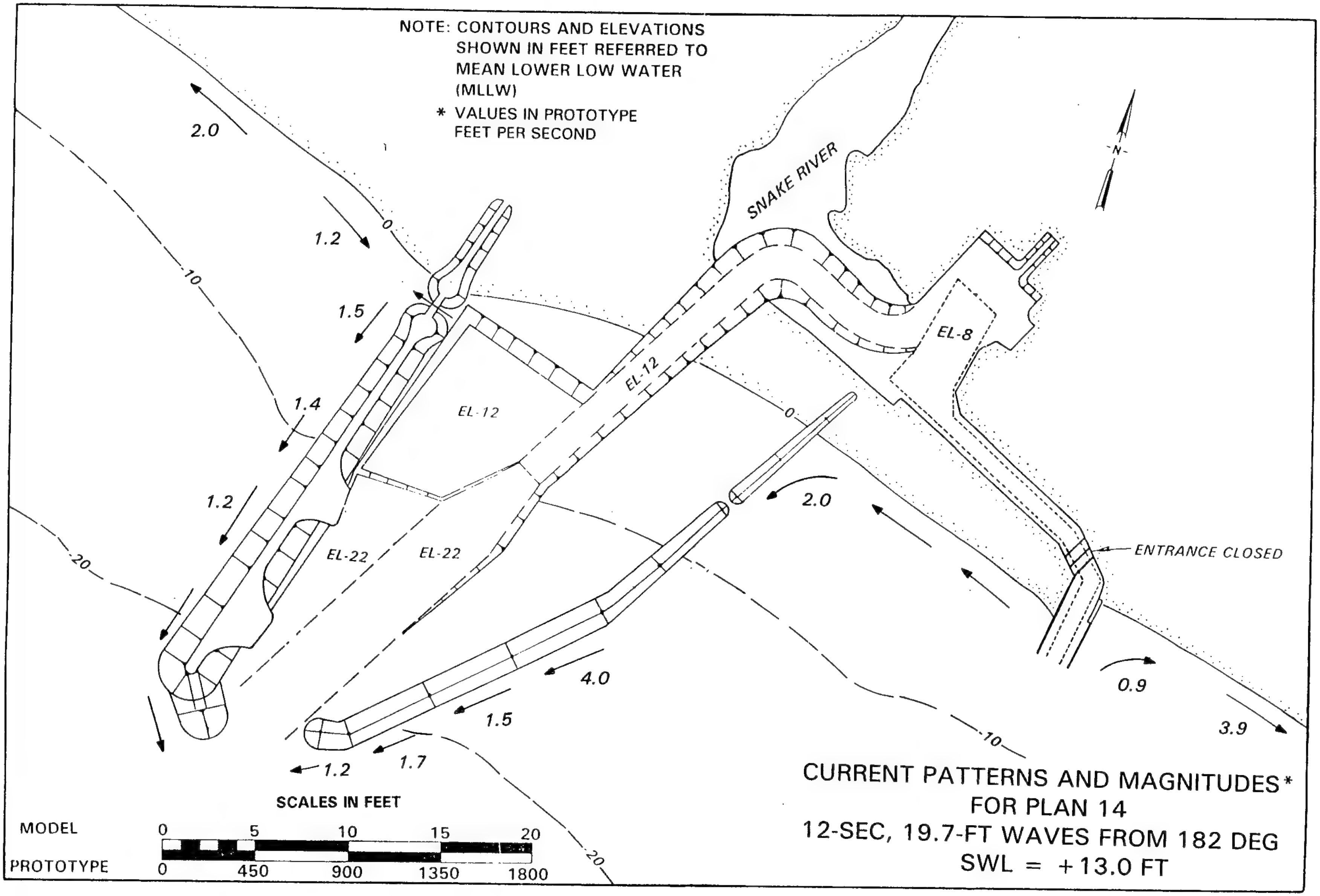
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 3.3-FT WAVES FROM 182 DEG
SWL = +1.6 FT



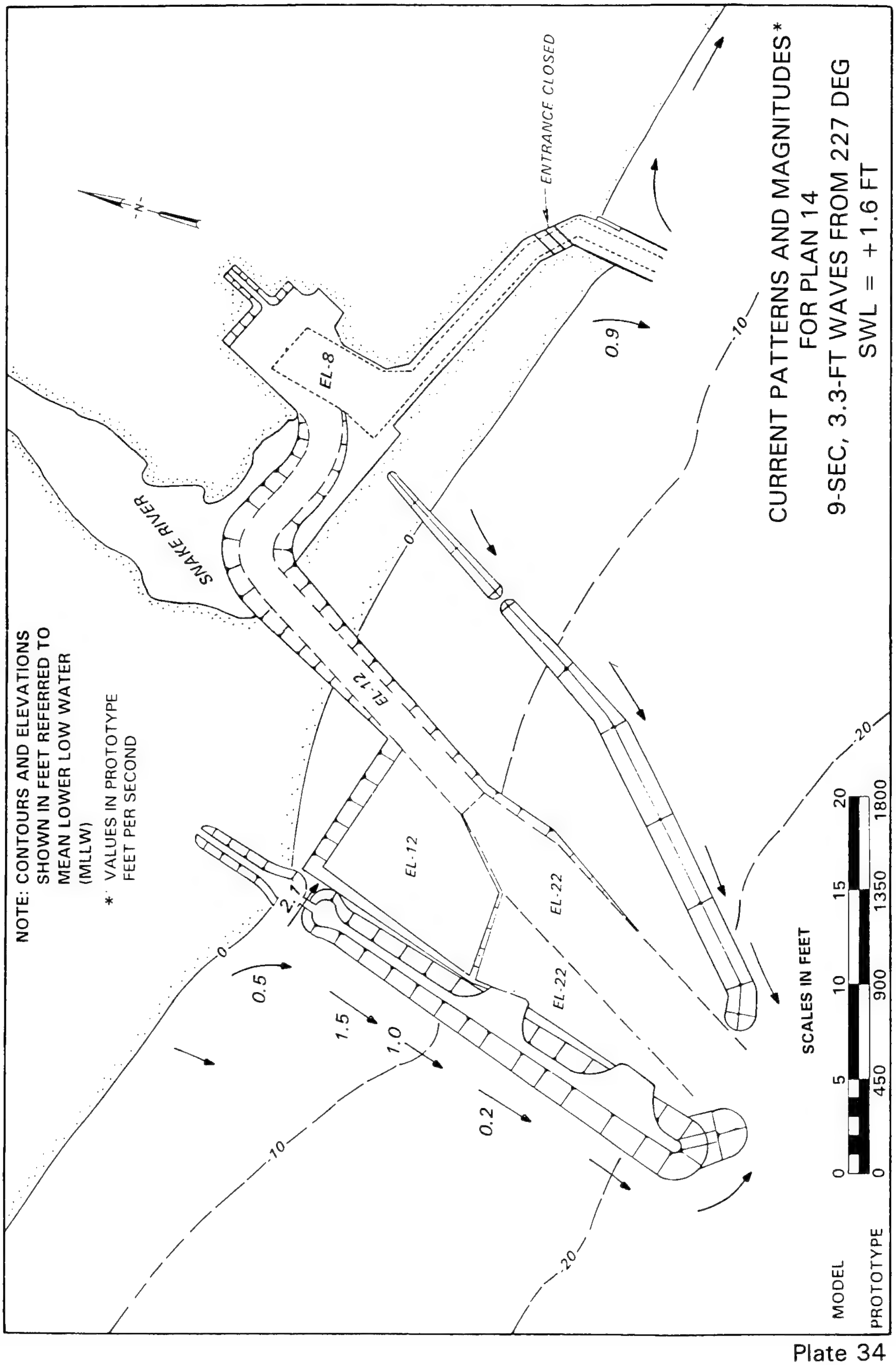
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT

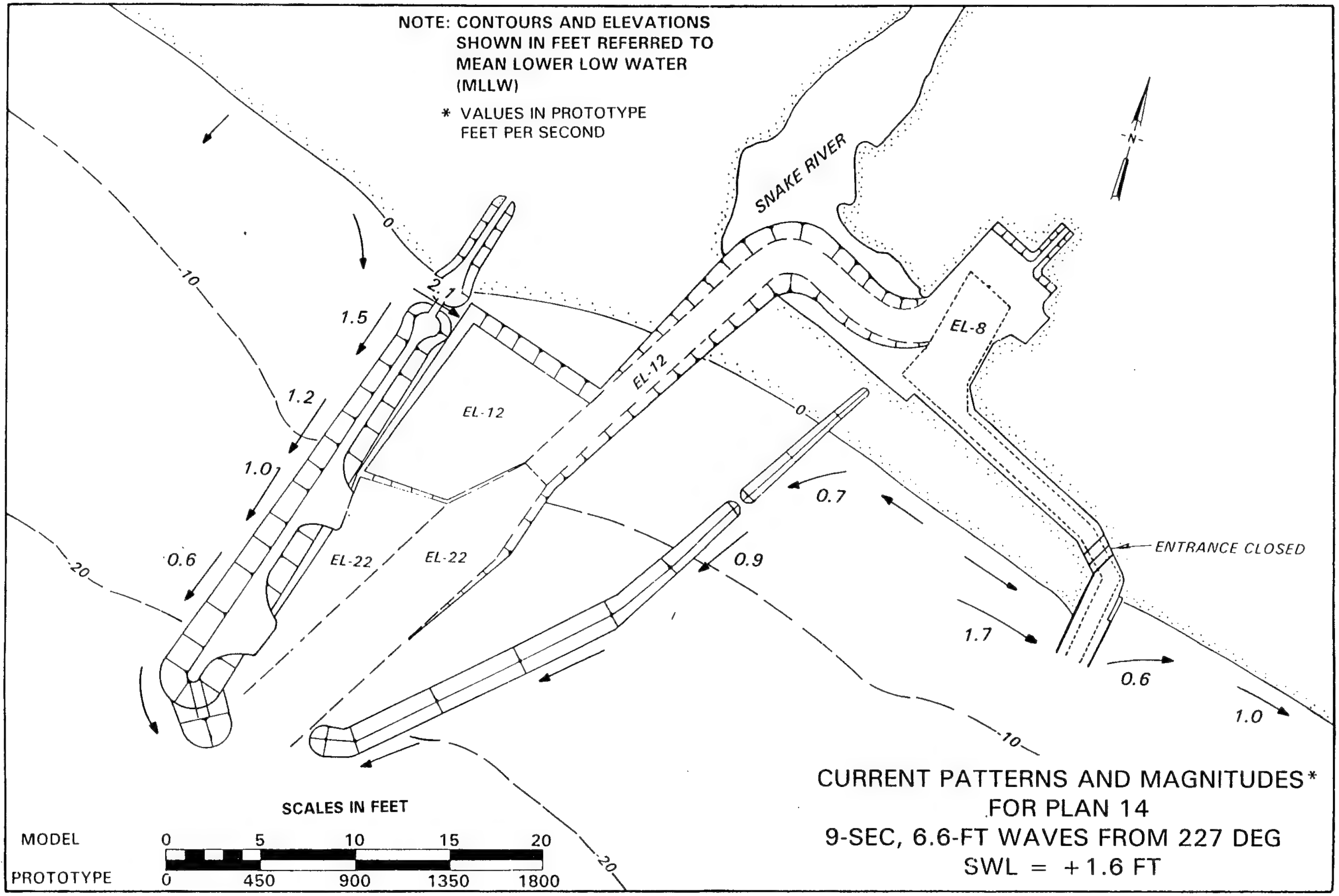


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 16.4-FT WAVES FROM 182 DEG
SWL = +1.6 FT

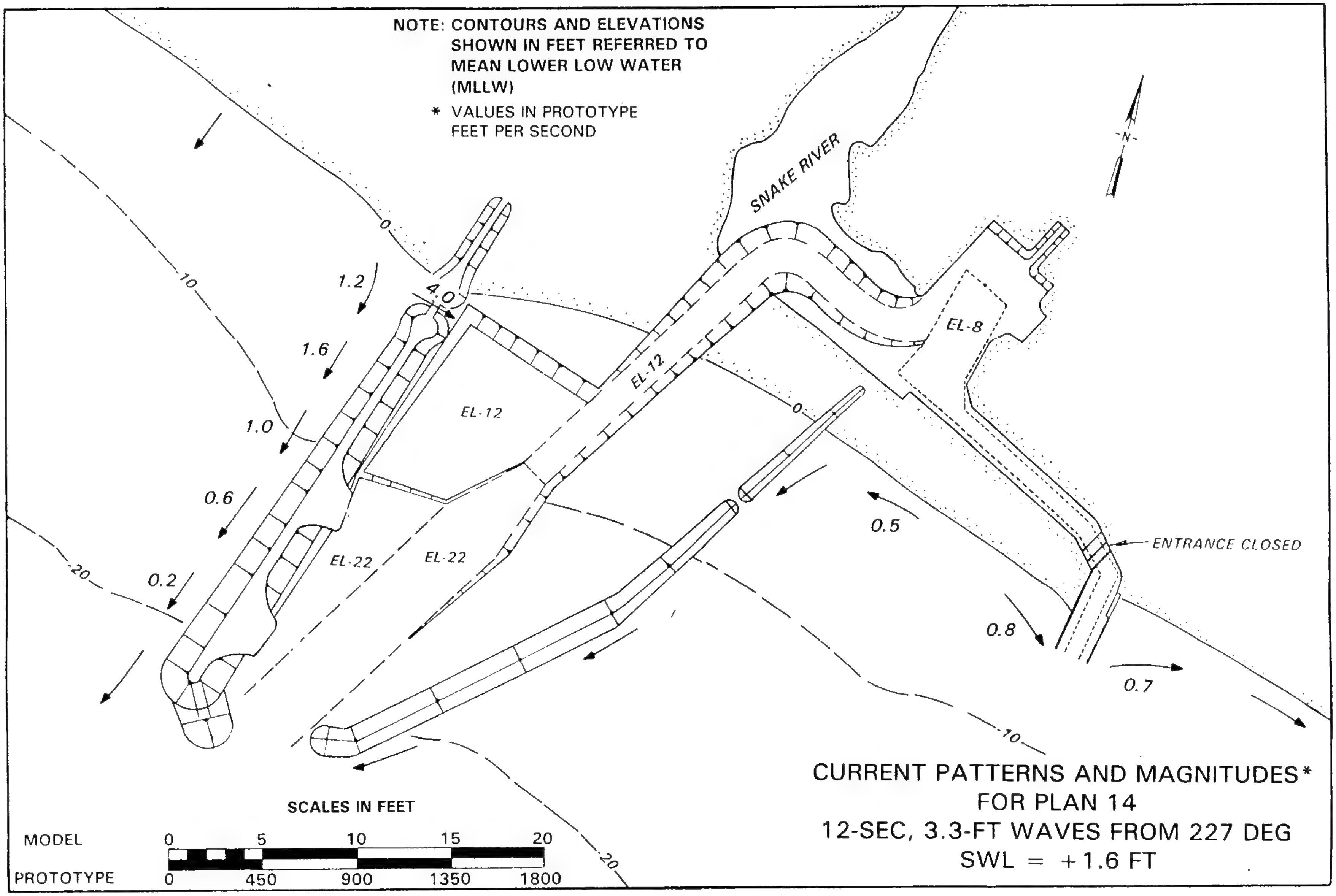


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 19.7-FT WAVES FROM 182 DEG
SWL = +13.0 FT

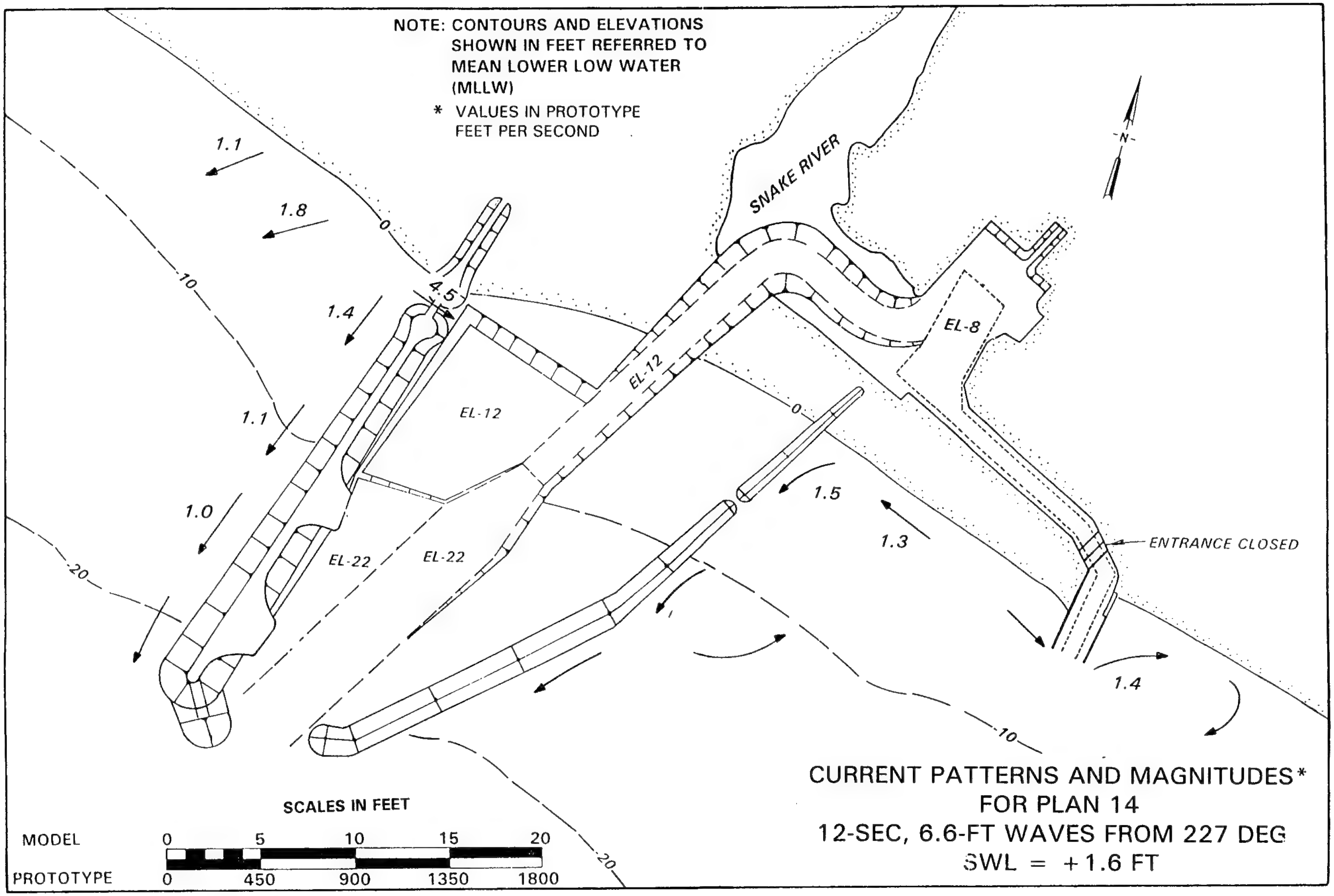

CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
9-SEC, 3.3-FT WAVES FROM 227 DEG
SWL = +1.6 FT
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
* VALUES IN PROTOTYPE FEET PER SECOND
ENTRANCE CLOSED
SNAKE RIVER
EL-8
EL-12
EL-12
EL-22
EL-22
0.9
0.5
1.5
1.0
0.2
2.1
0
0
10
10
20
20
SCALES IN FEET
MODEL
PROTOTYPE
0 5 10 15 20
0 450 900 1350 1800



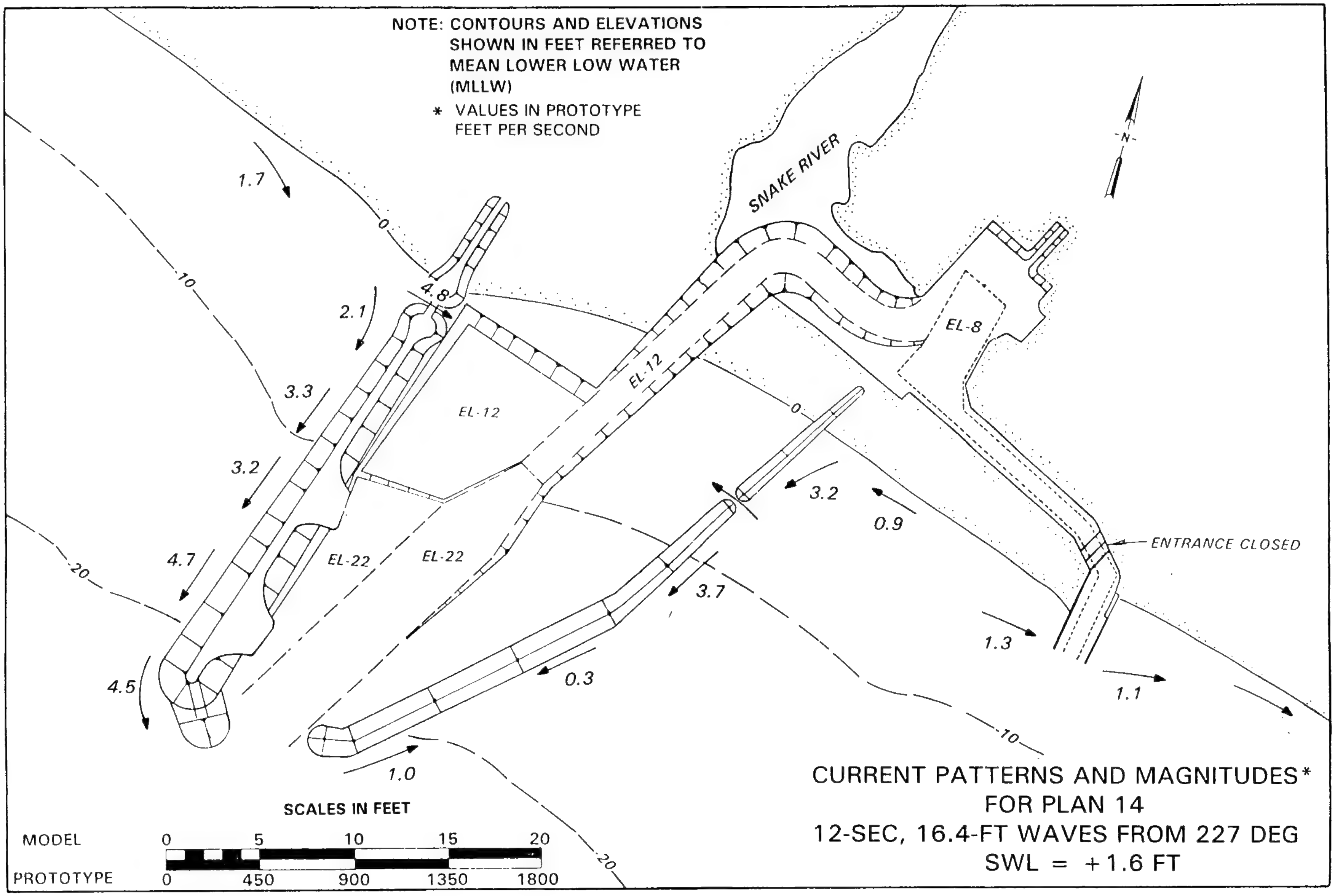
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
9-SEC, 6.6-FT WAVES FROM 227 DEG
SWL = +1.6 FT



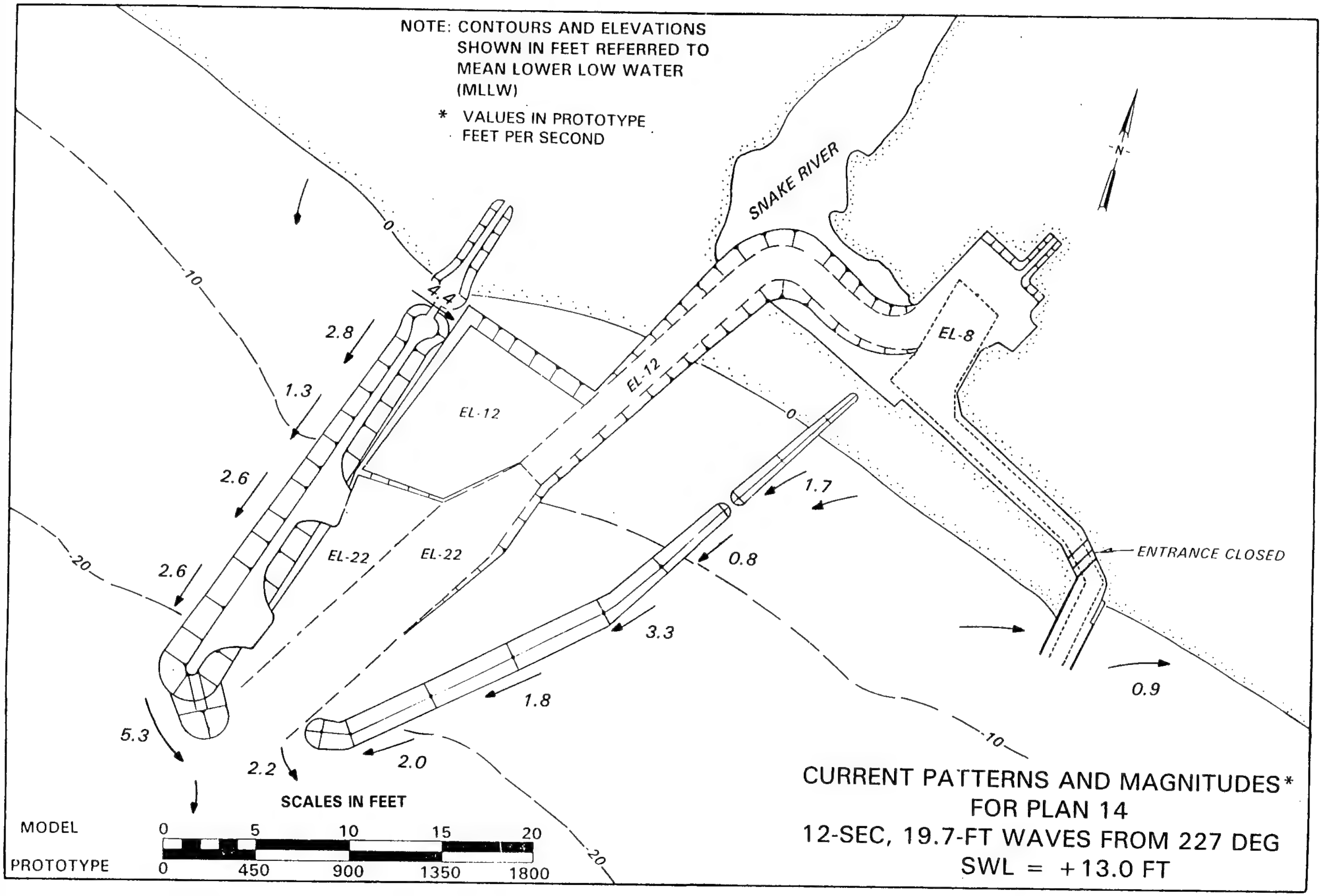
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 3.3-FT WAVES FROM 227 DEG
SWL = +1.6 FT



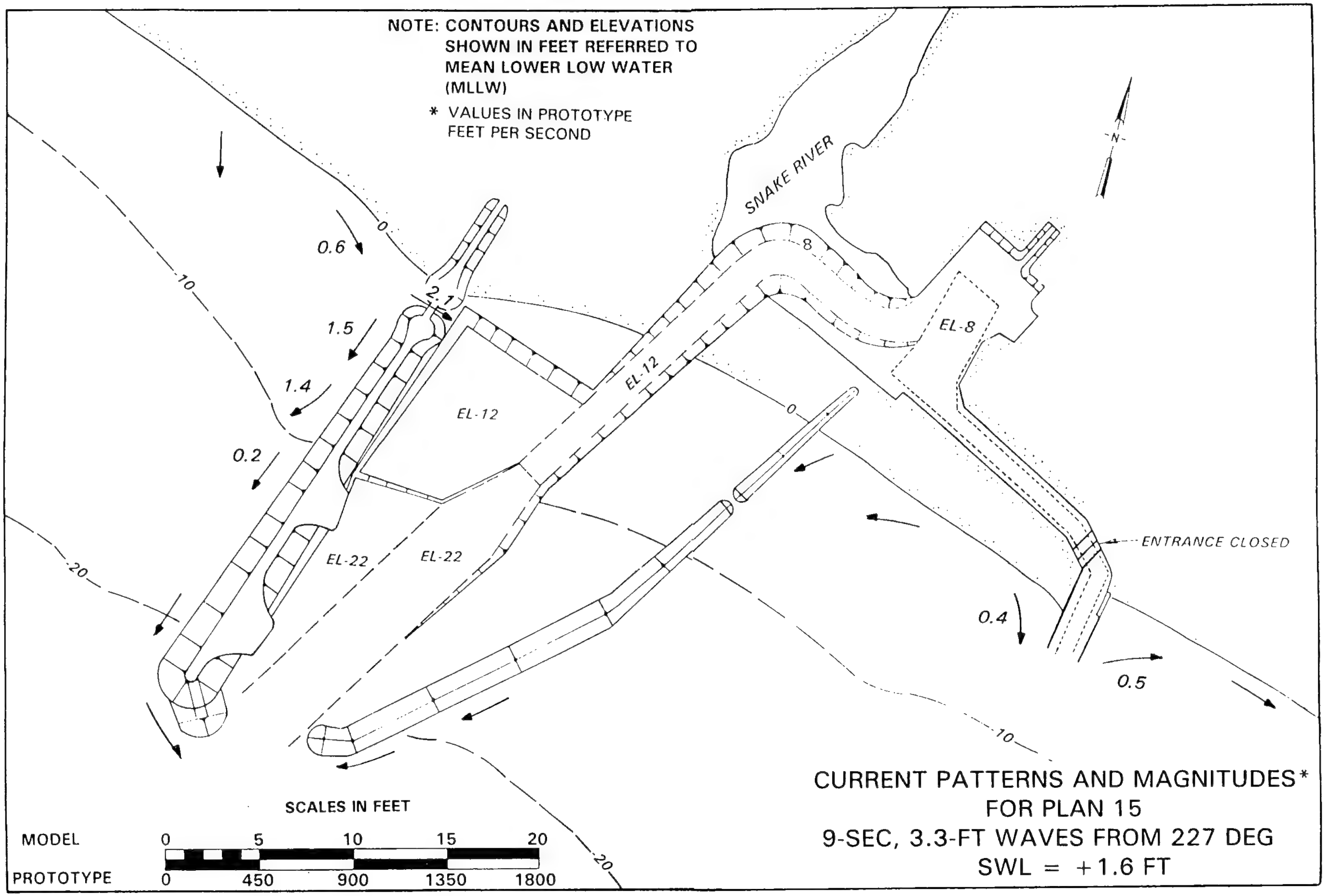
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 6.6-FT WAVES FROM 227 DEG
SWL = +1.6 FT



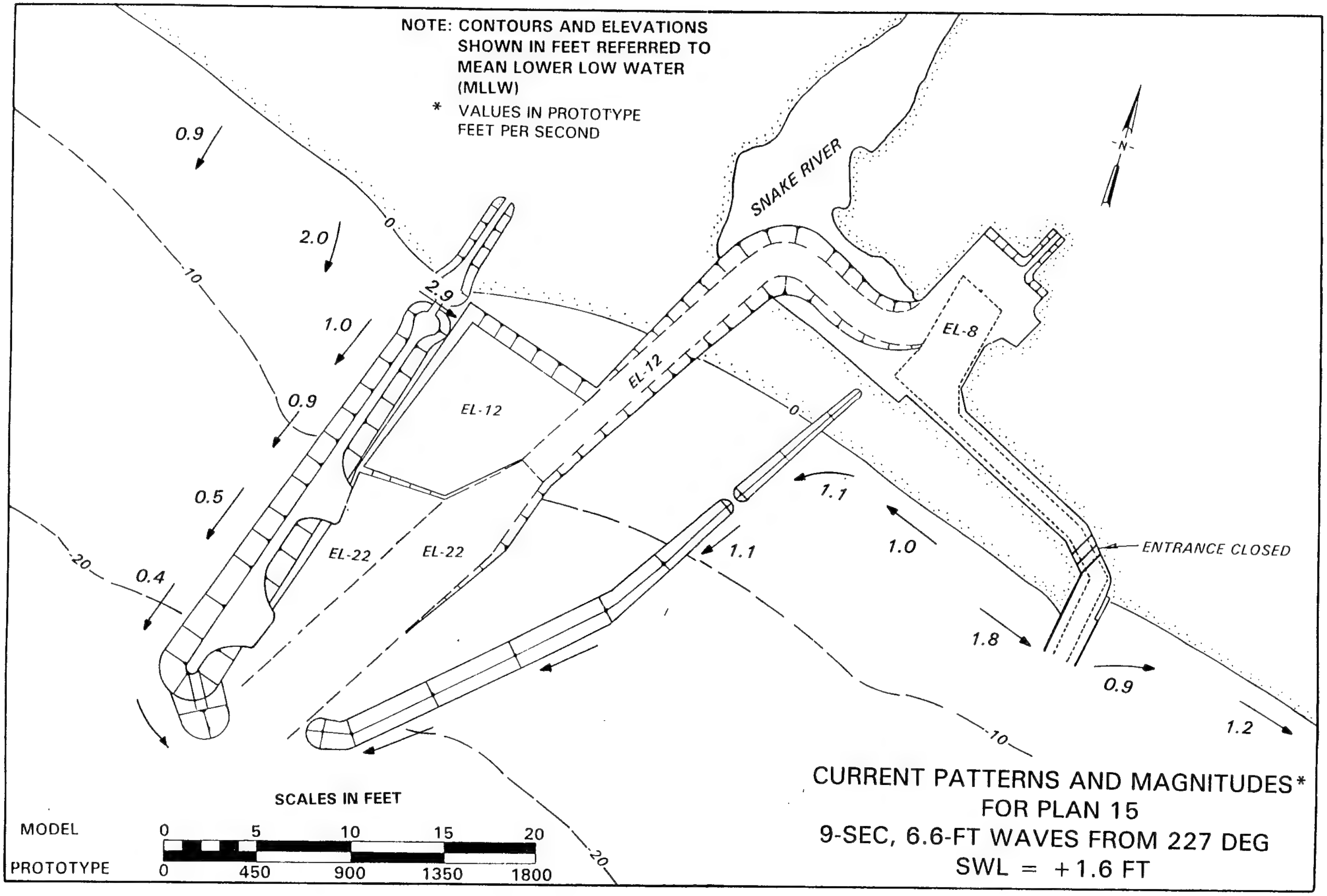
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 16.4-FT WAVES FROM 227 DEG
SWL = +1.6 FT



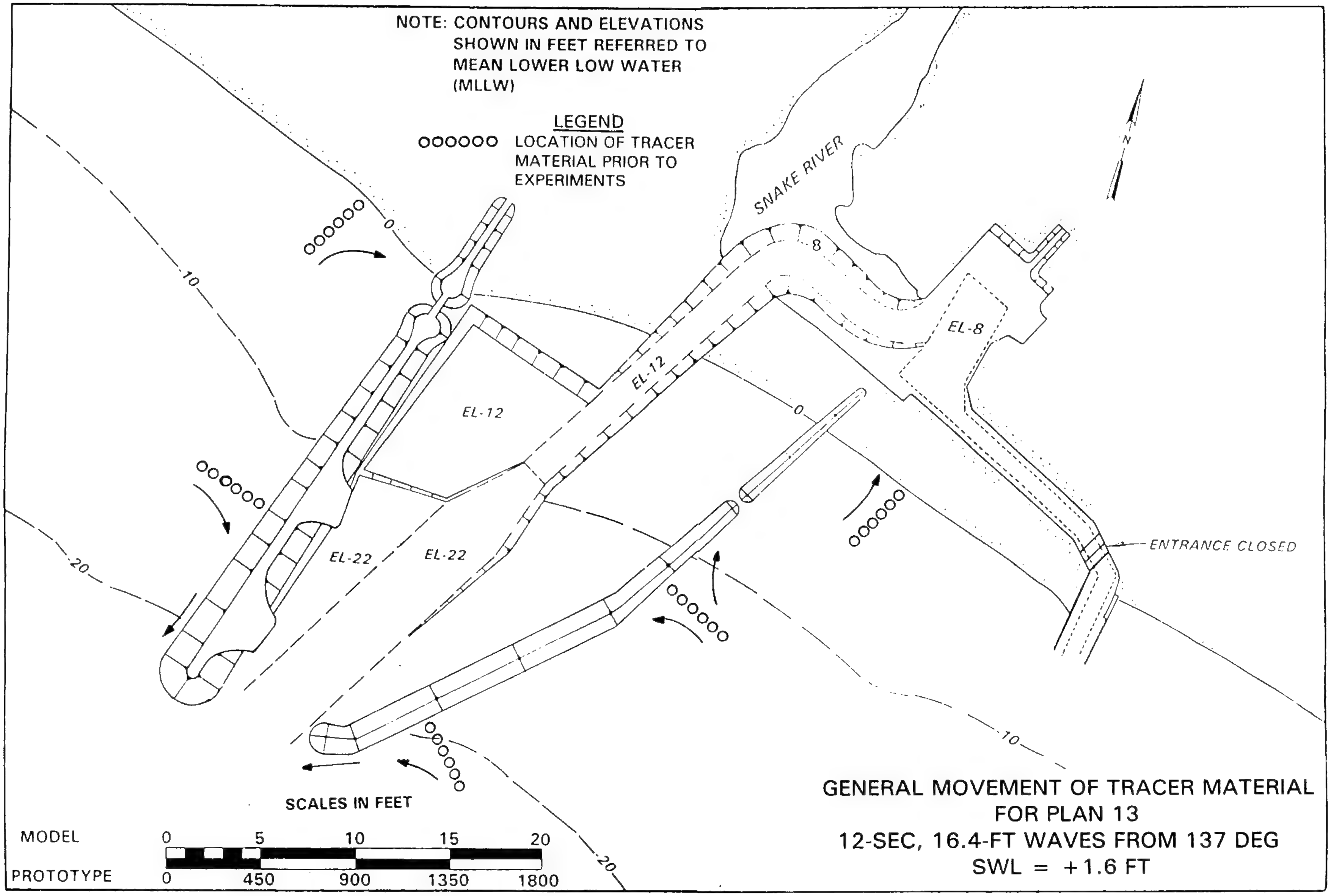
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 14
12-SEC, 19.7-FT WAVES FROM 227 DEG
SWL = +13.0 FT



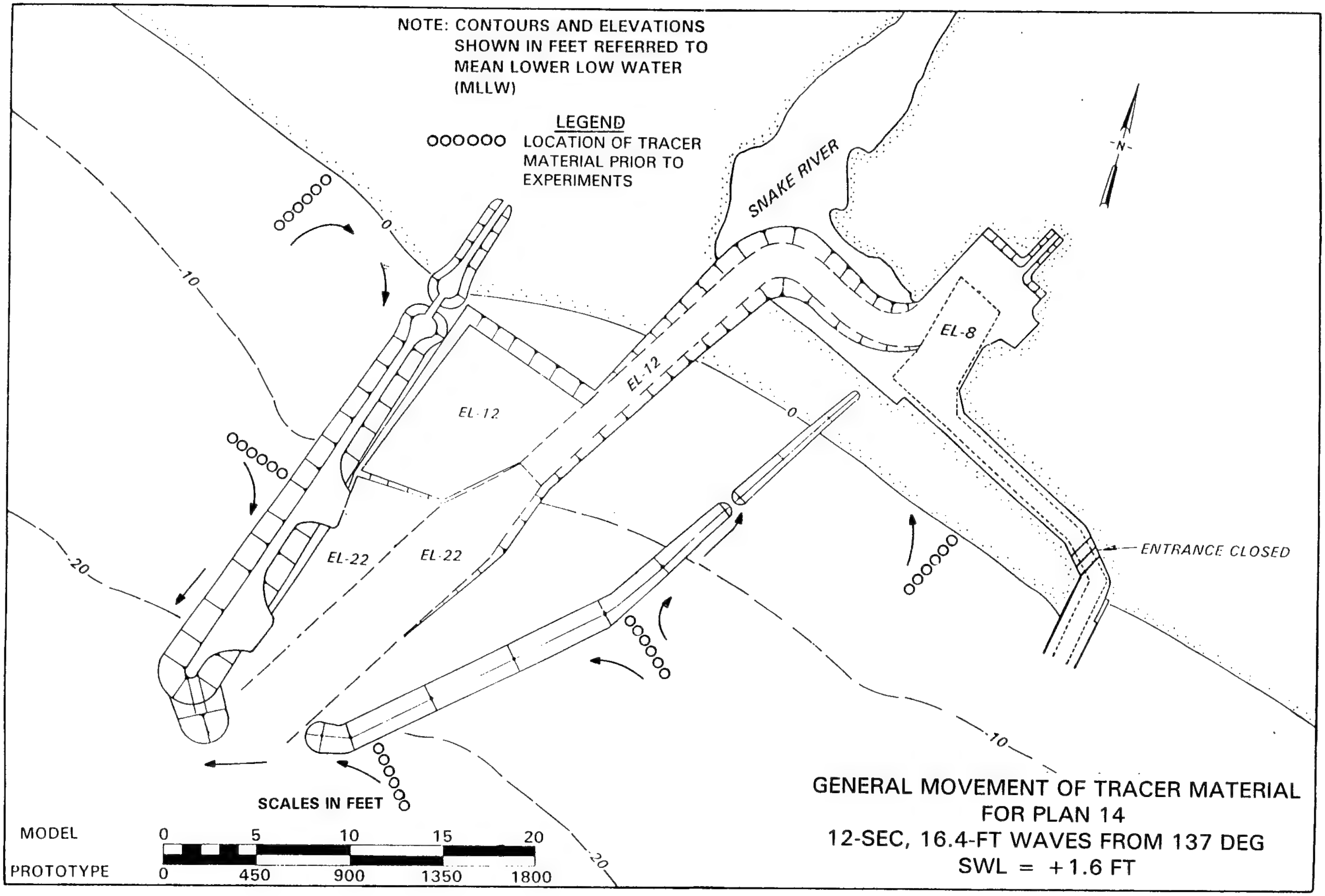
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 15
9-SEC, 3.3-FT WAVES FROM 227 DEG
SWL = +1.6 FT



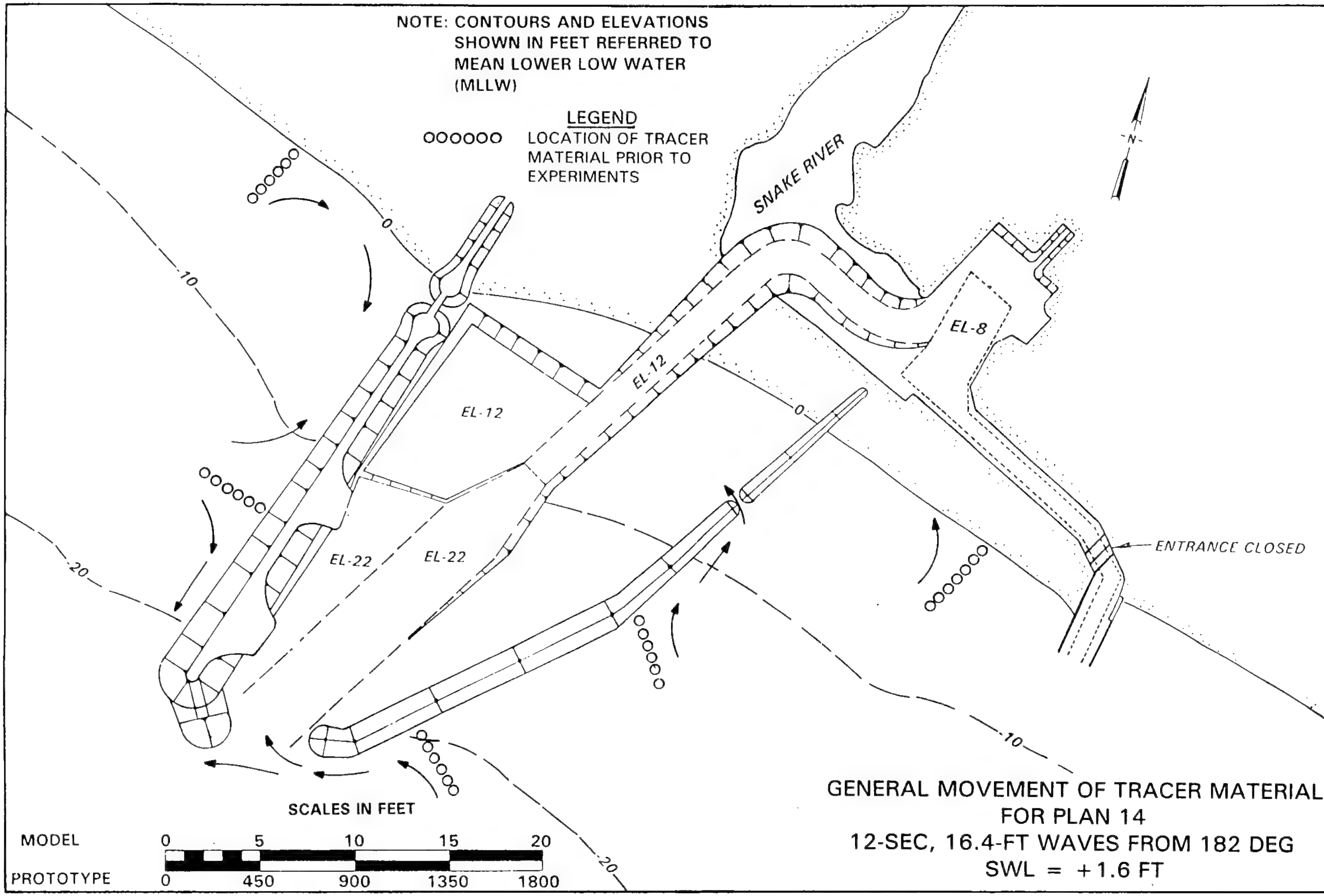
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 15
9-SEC, 6.6-FT WAVES FROM 227 DEG
SWL = +1.6 FT



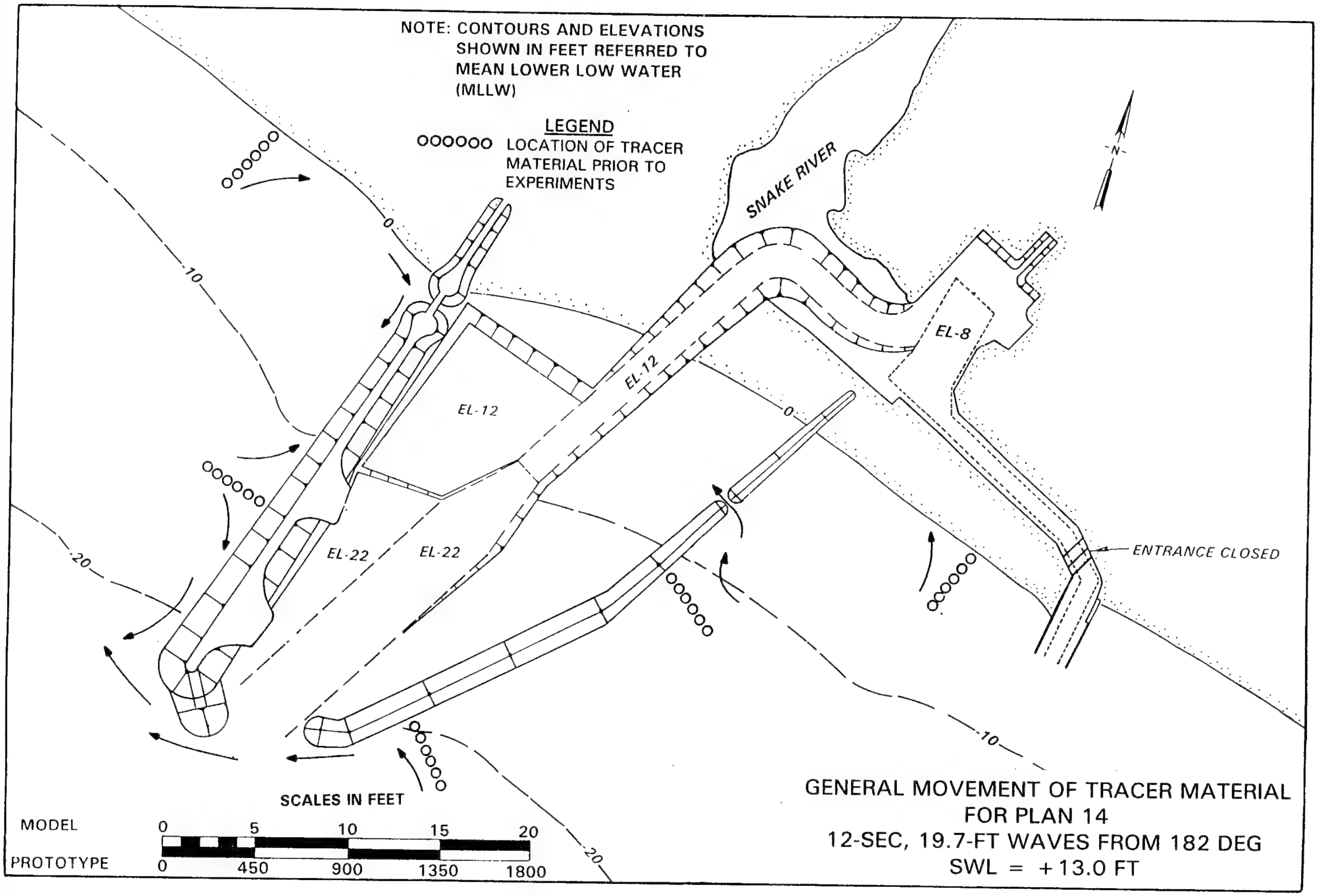
GENERAL MOVEMENT OF TRACER MATERIAL FOR PLAN 13
12-SEC, 16.4-FT WAVES FROM 137 DEG
SWL = +1.6 FT



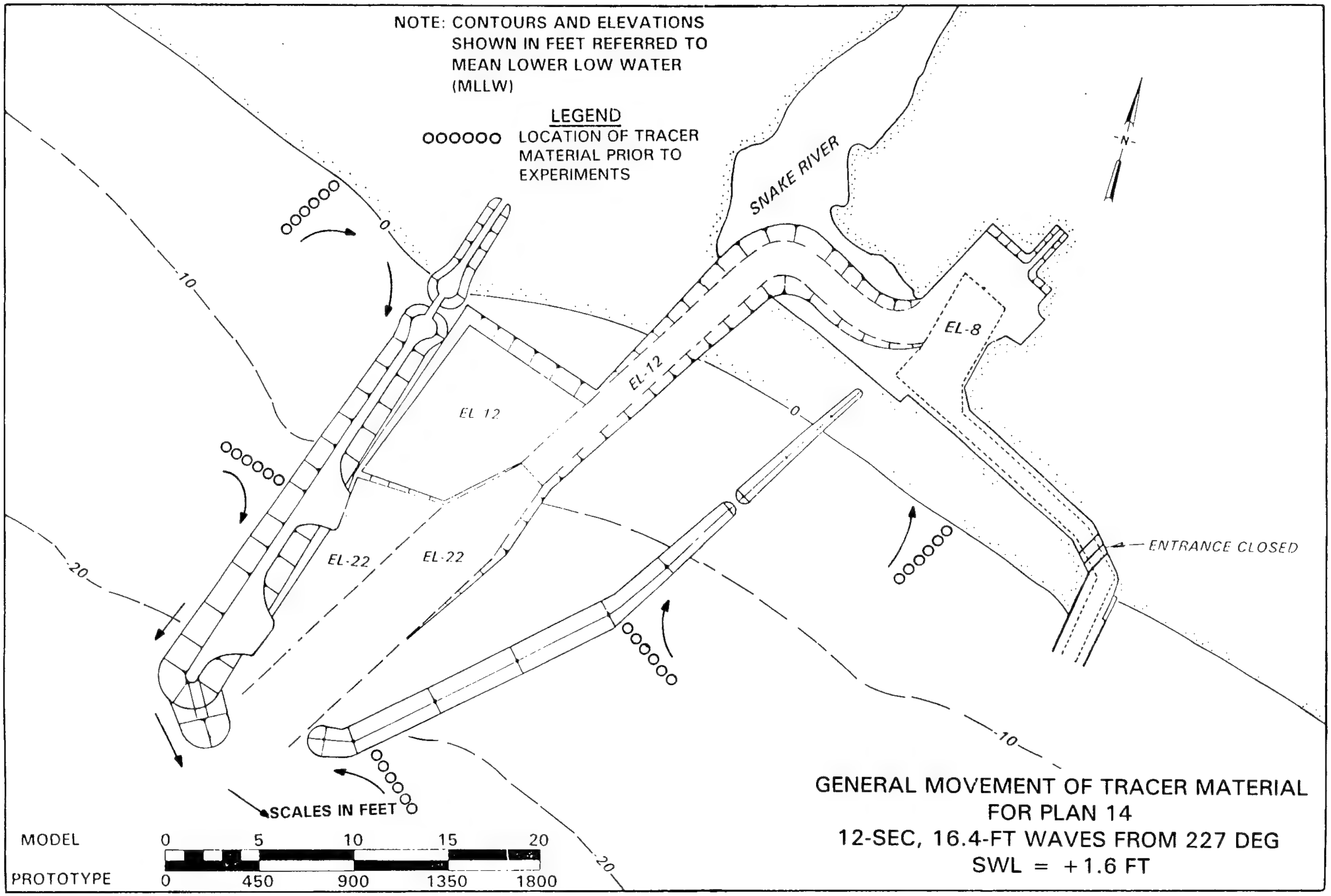
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 14
12-SEC, 16.4-FT WAVES FROM 137 DEG
SWL = +1.6 FT



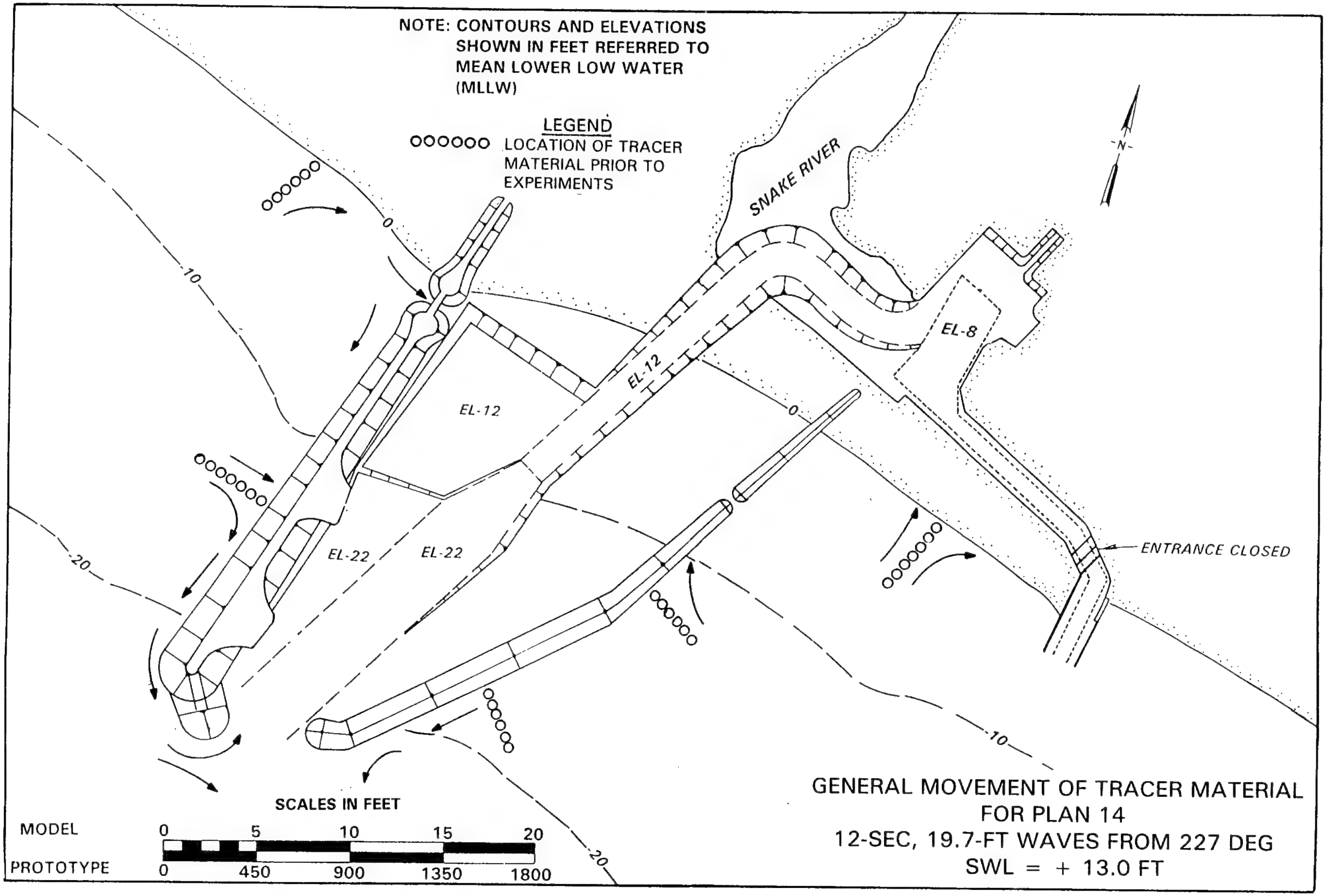
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 14
12-SEC, 16.4-FT WAVES FROM 182 DEG
SWL = +1.6 FT



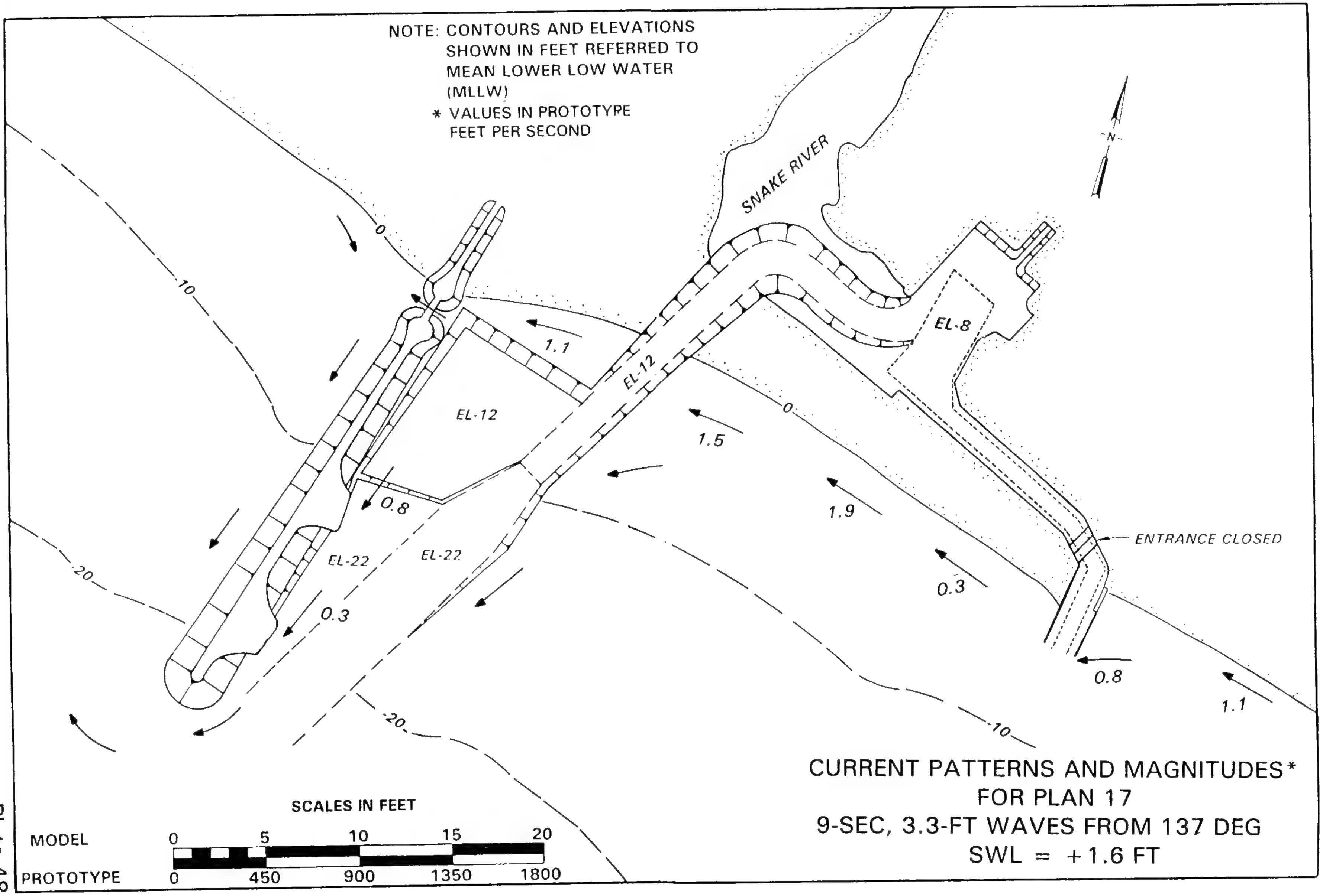
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 14
12-SEC, 19.7-FT WAVES FROM 182 DEG
SWL = +13.0 FT



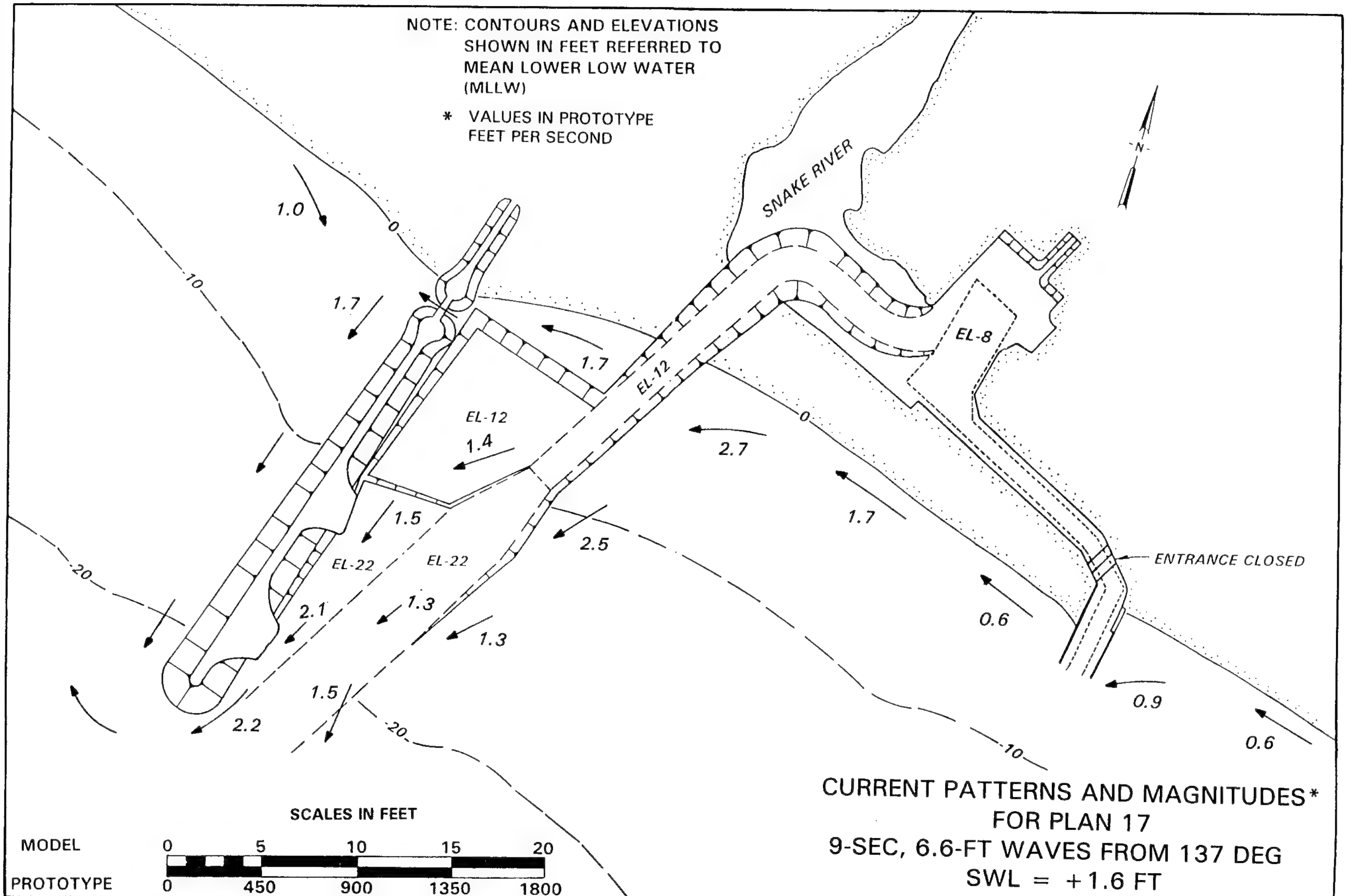
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 14
12-SEC, 16.4-FT WAVES FROM 227 DEG
SWL = +1.6 FT



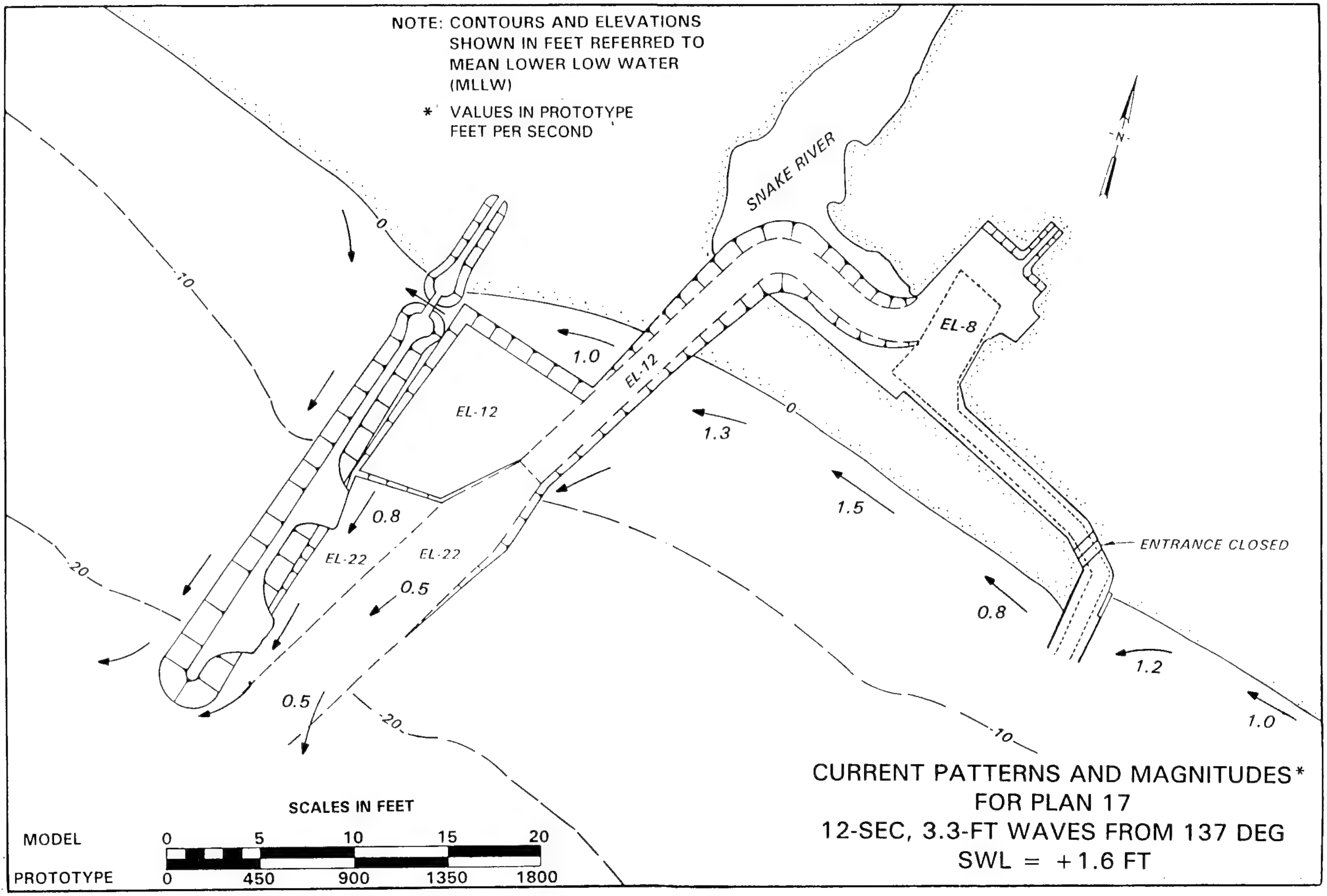
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 14
12-SEC, 19.7-FT WAVES FROM 227 DEG
SWL = + 13.0 FT

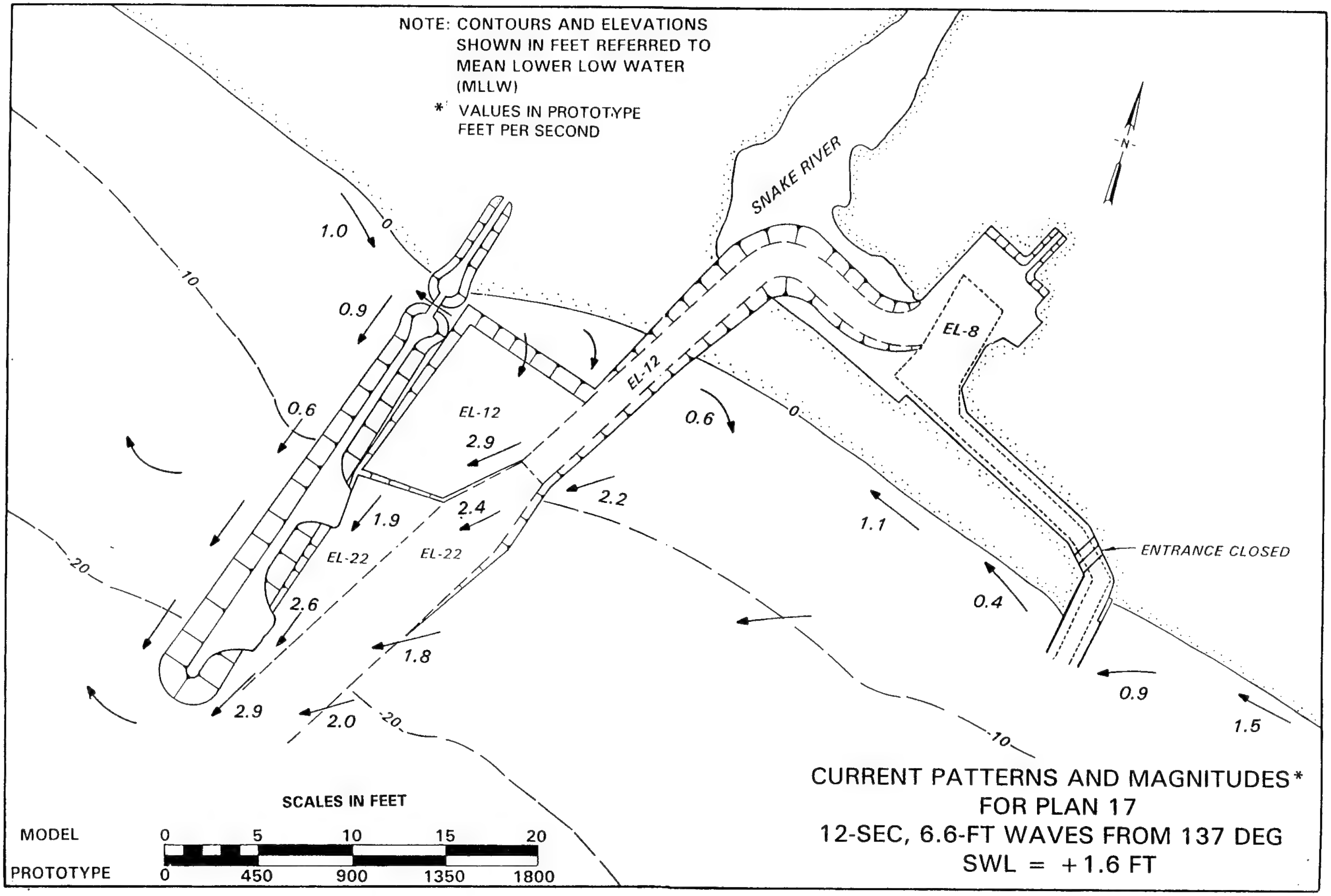


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
9-SEC, 3.3-FT WAVES FROM 137 DEG
SWL = +1.6 FT

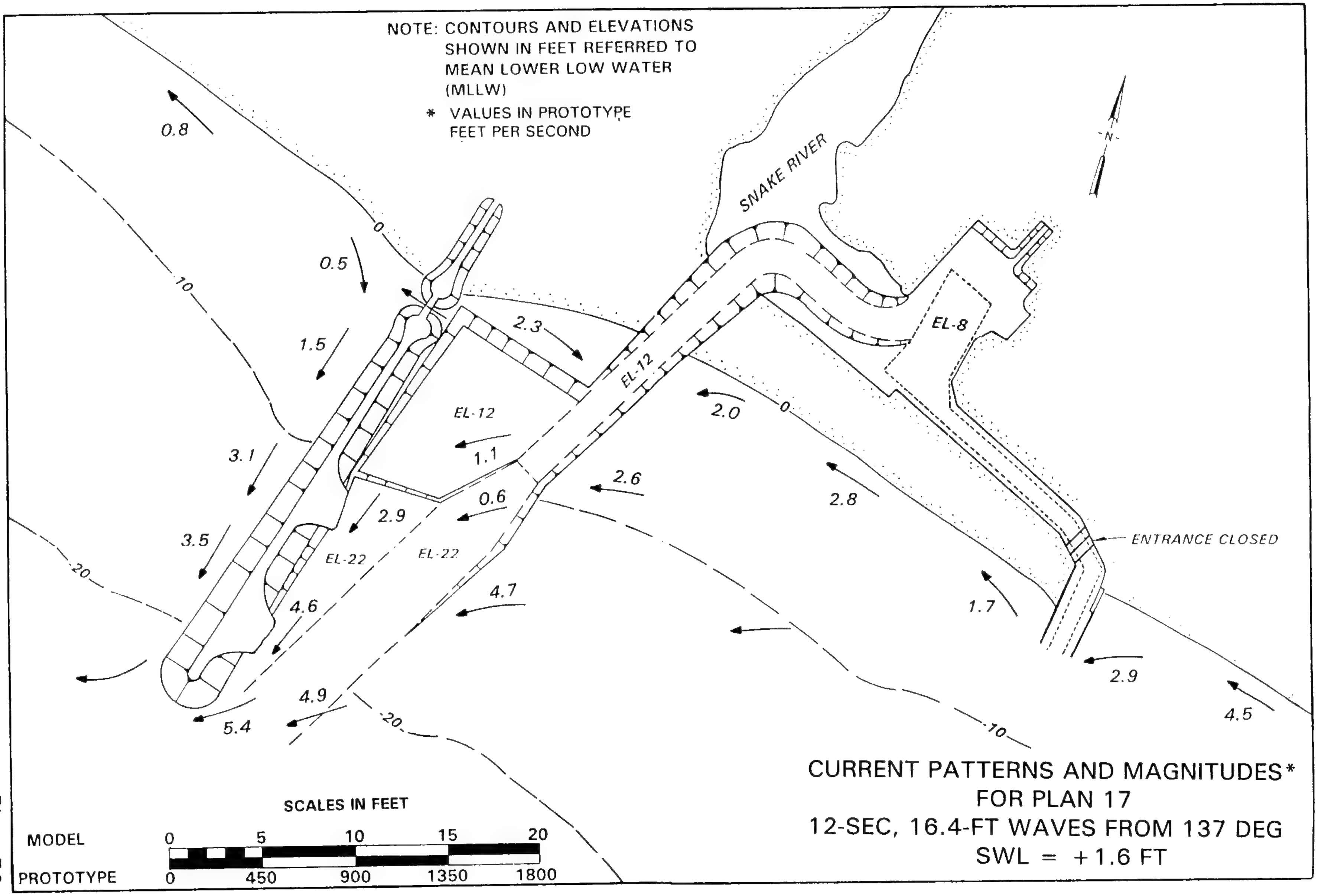


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
9-SEC, 6.6-FT WAVES FROM 137 DEG
SWL = +1.6 FT

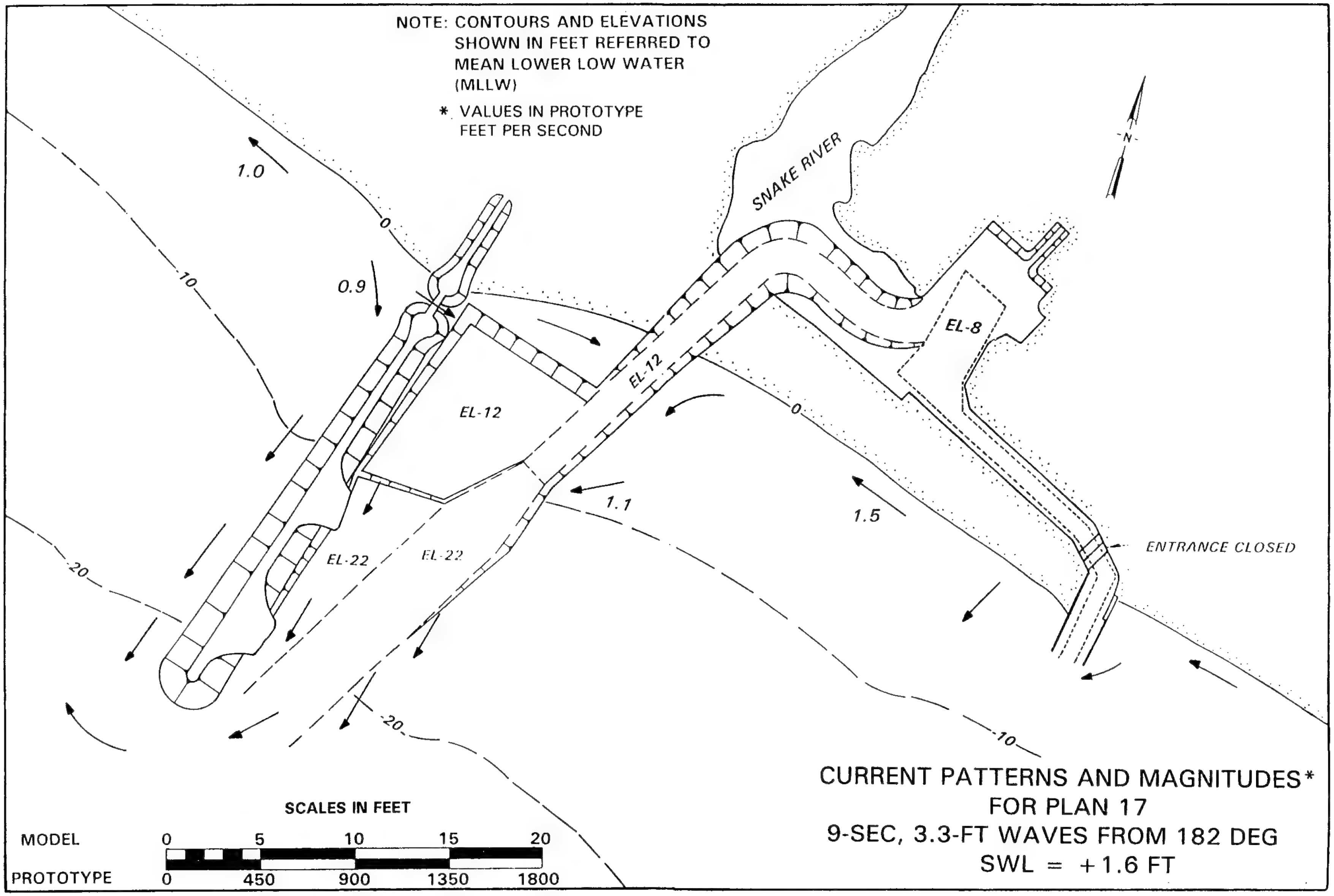

NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
* VALUES IN PROTOTYPE FEET PER SECOND
SNAKE RIVER
N
EL-8
EL-12
EL-12
EL-22
EL-22
ENTRANCE CLOSED
0
0
10
10
20
20
1.0
1.3
1.5
0.8
1.2
1.0
0.8
0.5
0.5
SCALES IN FEET
MODEL 0 5 10 15 20
PROTOTYPE 0 450 900 1350 1800
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 3.3-FT WAVES FROM 137 DEG
SWL = +1.6 FT



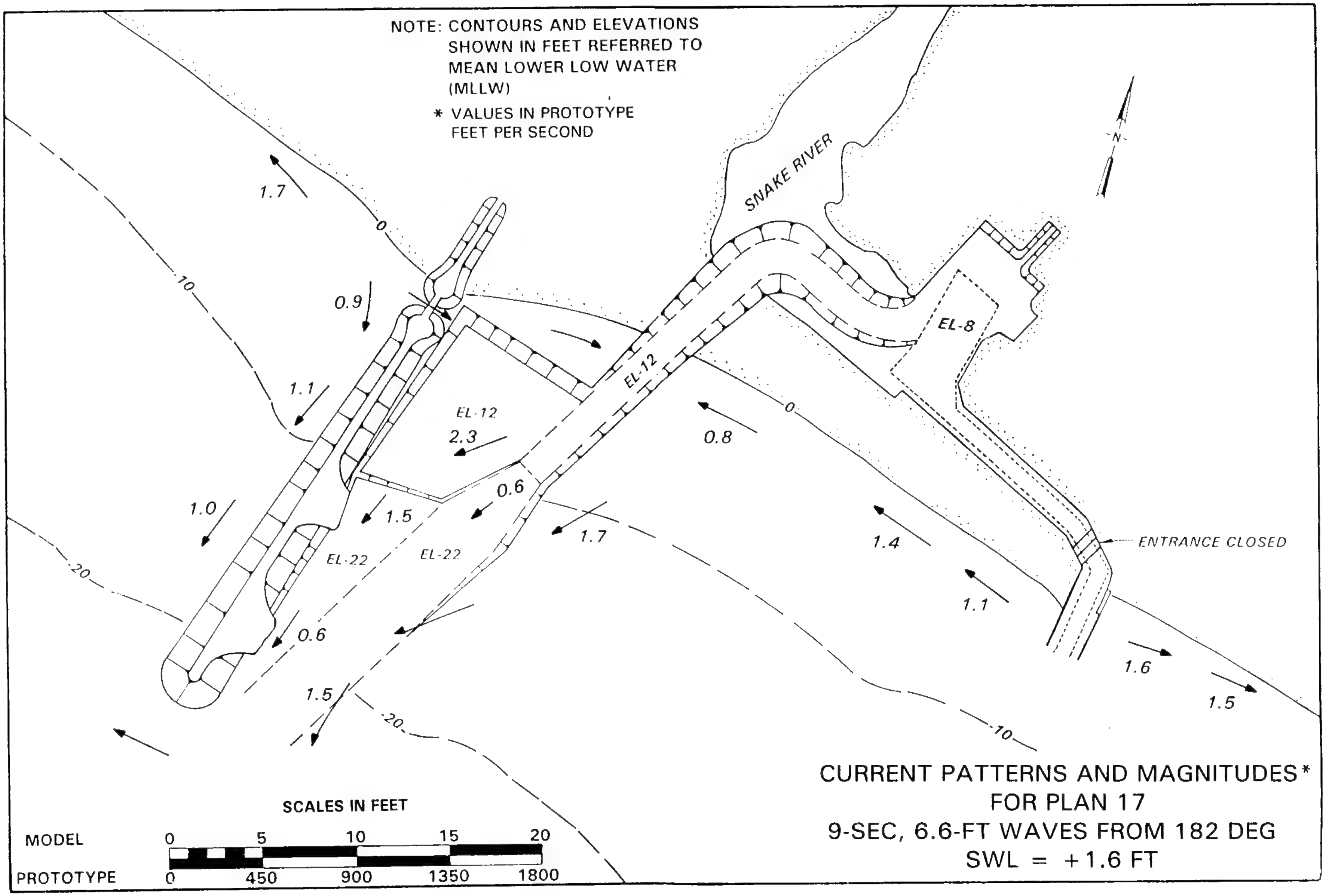
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 6.6-FT WAVES FROM 137 DEG
SWL = +1.6 FT



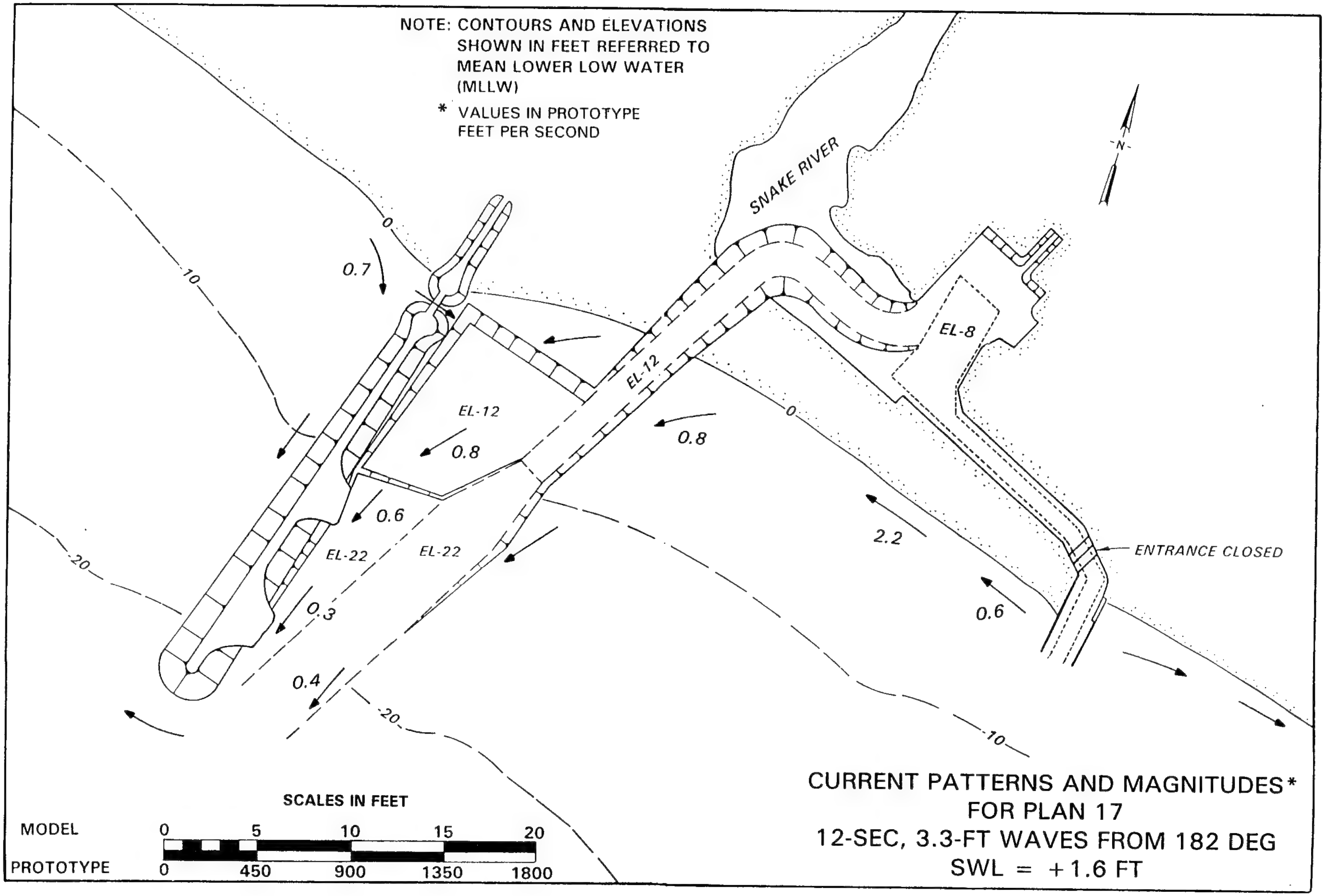
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 16.4-FT WAVES FROM 137 DEG
SWL = +1.6 FT



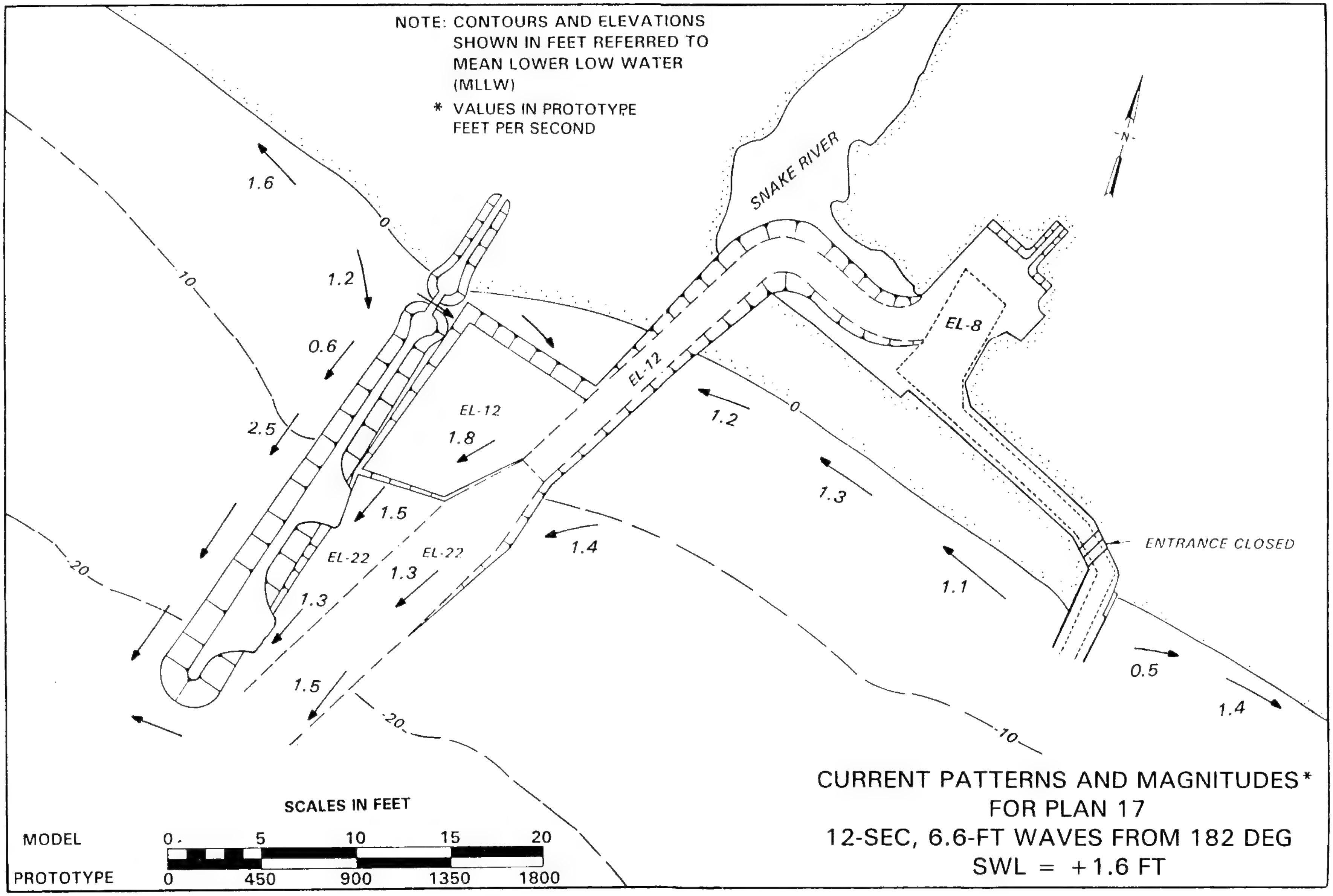
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
9-SEC, 3.3-FT WAVES FROM 182 DEG
SWL = +1.6 FT



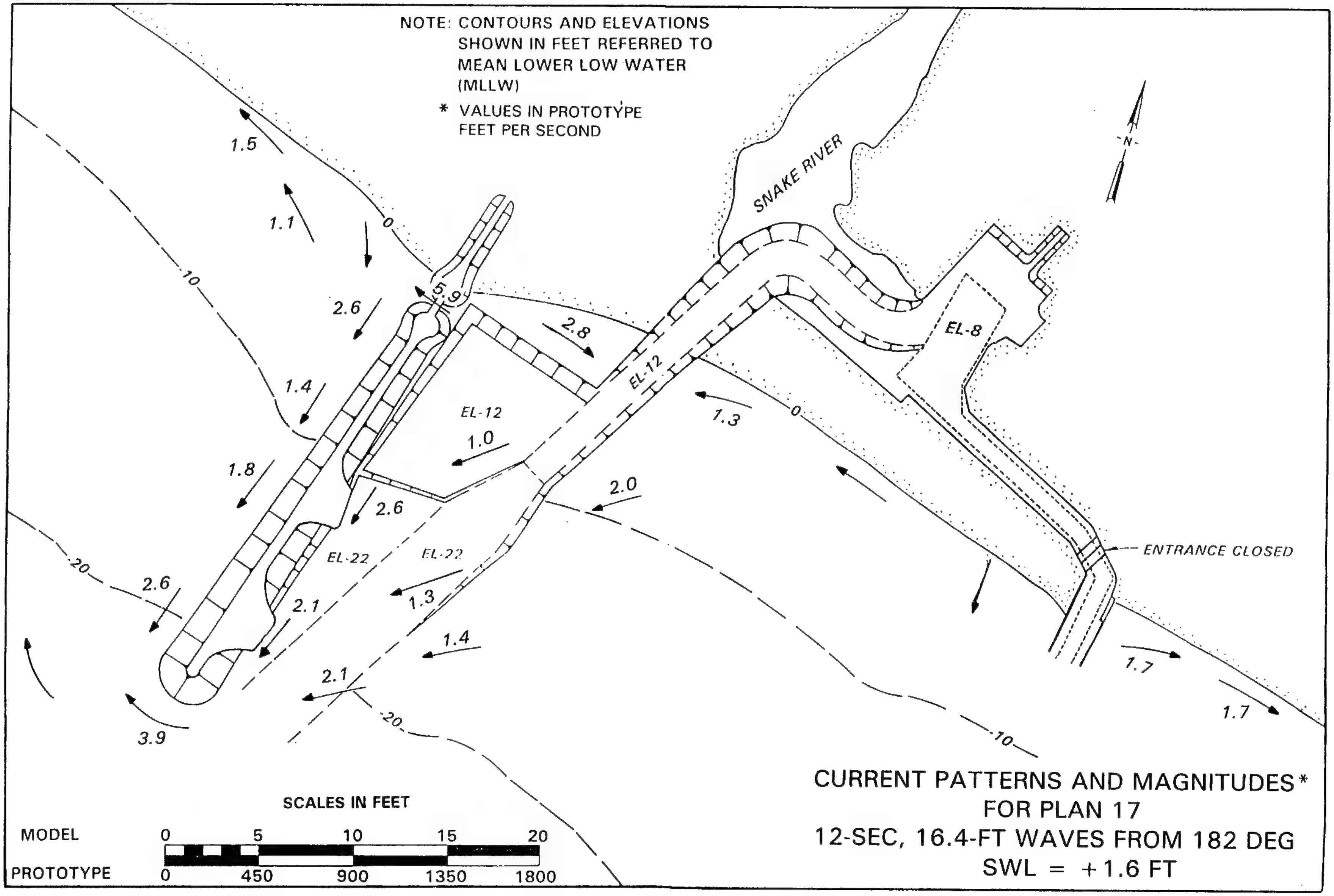
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
9-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT



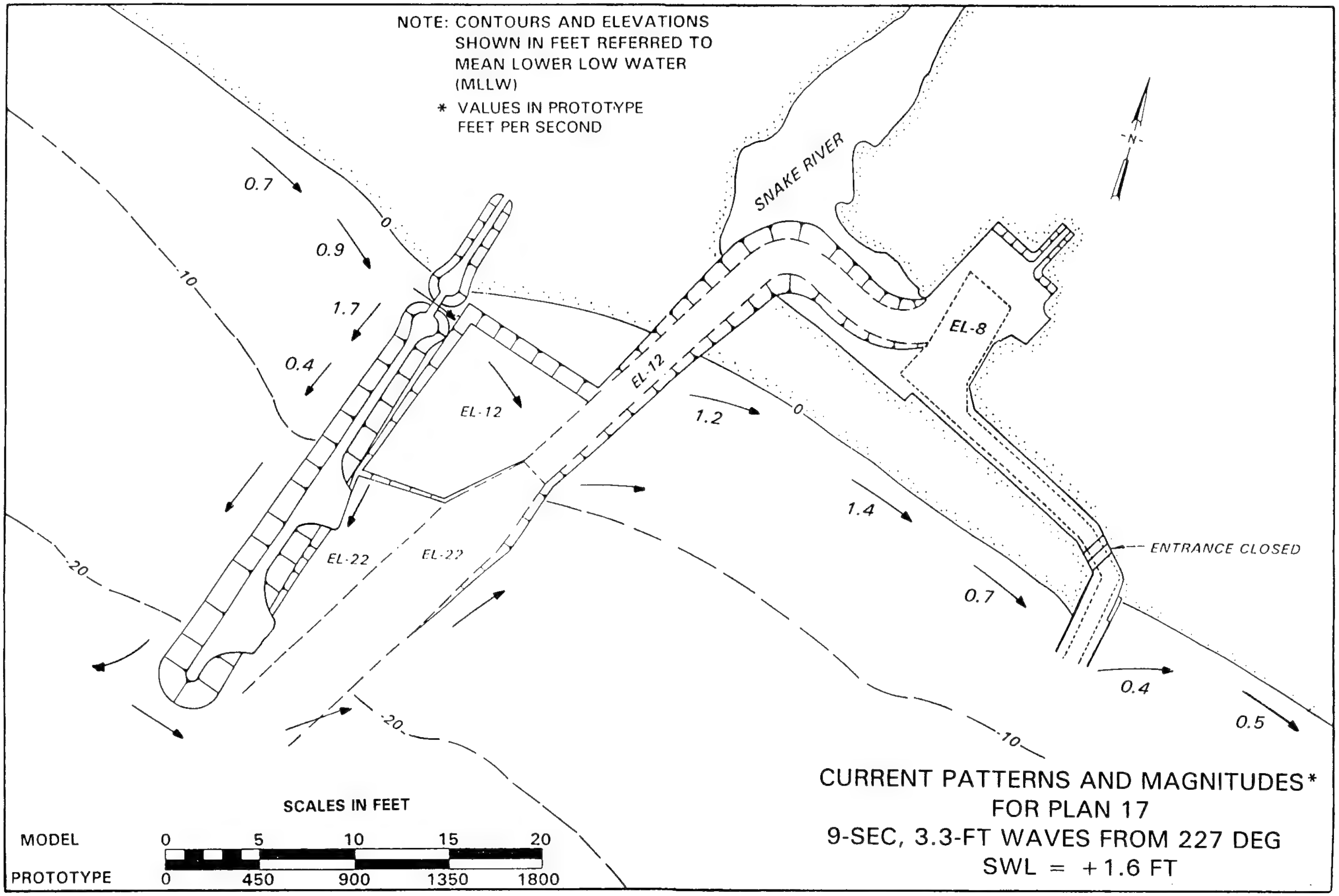
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 3.3-FT WAVES FROM 182 DEG
SWL = +1.6 FT



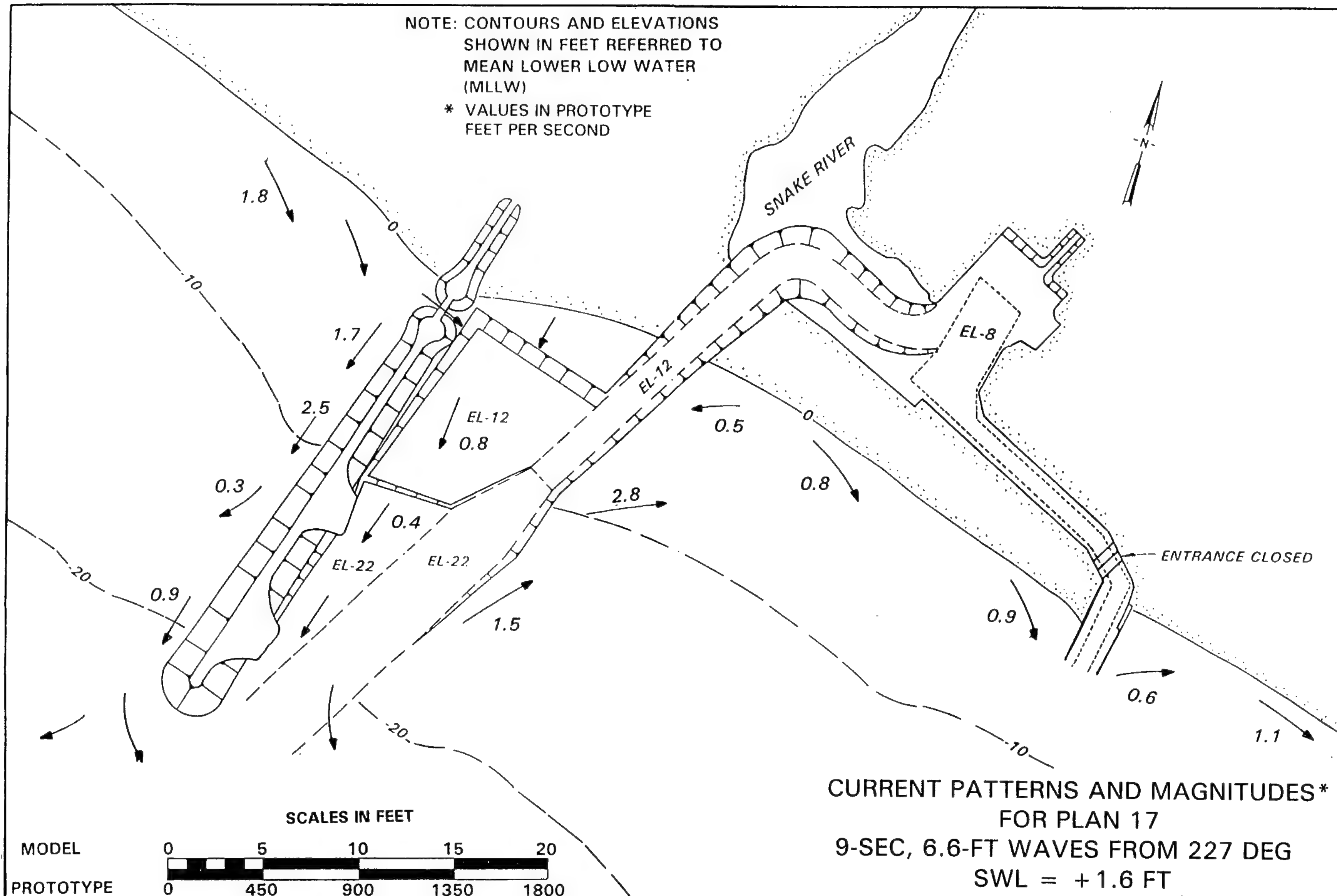
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 6.6-FT WAVES FROM 182 DEG
SWL = +1.6 FT



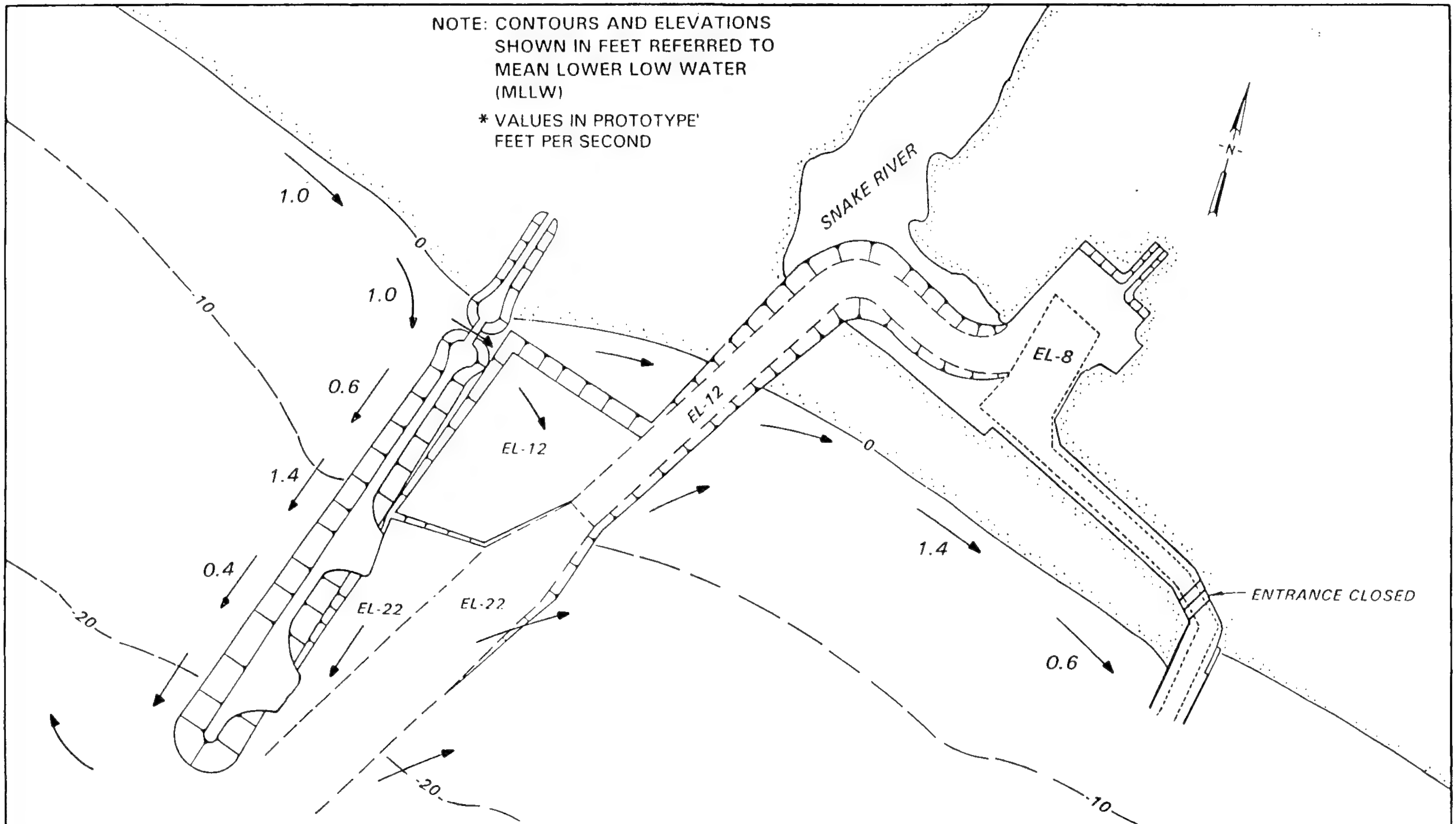
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 16.4-FT WAVES FROM 182 DEG
SWL = +1.6 FT



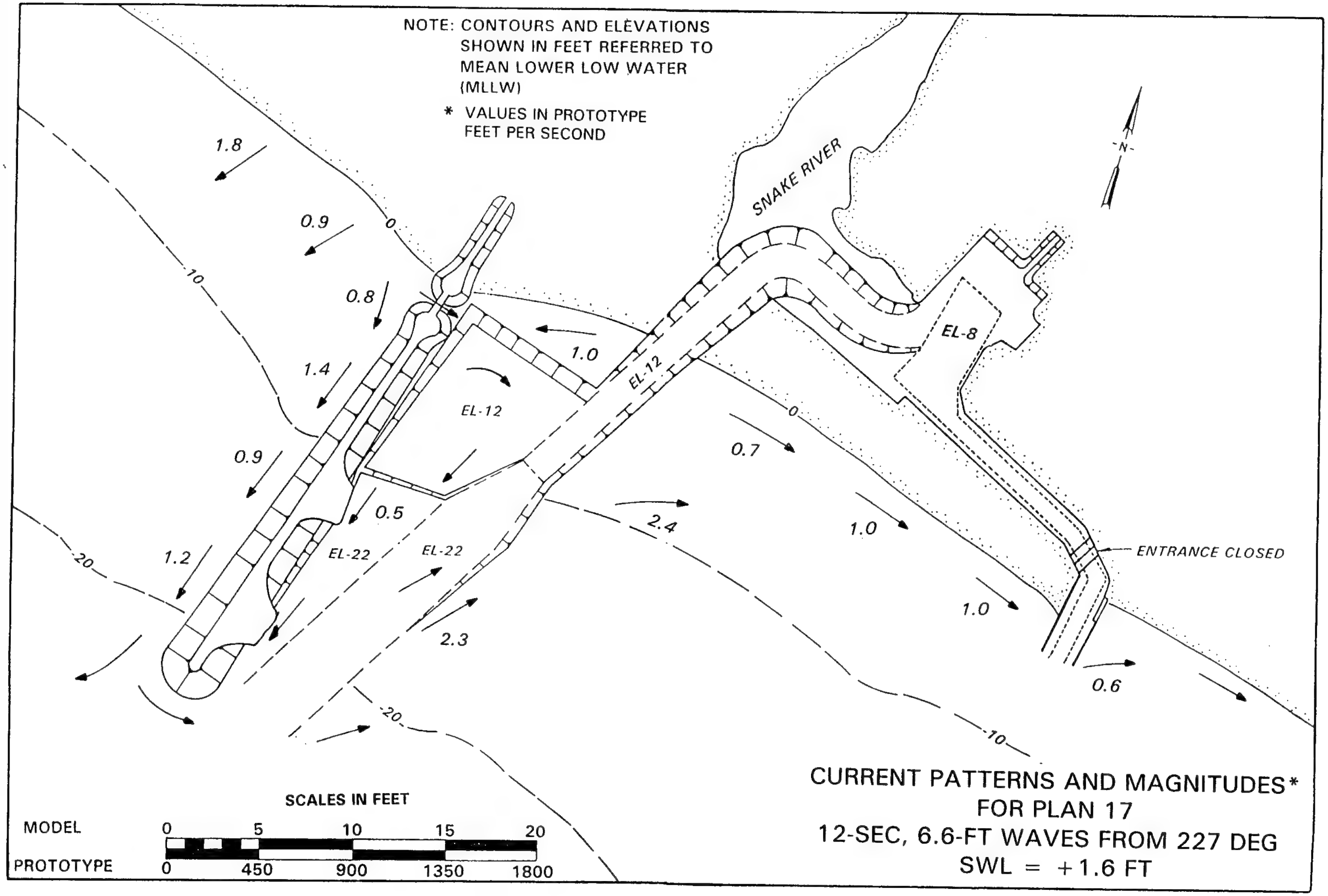
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
9-SEC, 3.3-FT WAVES FROM 227 DEG
SWL = +1.6 FT



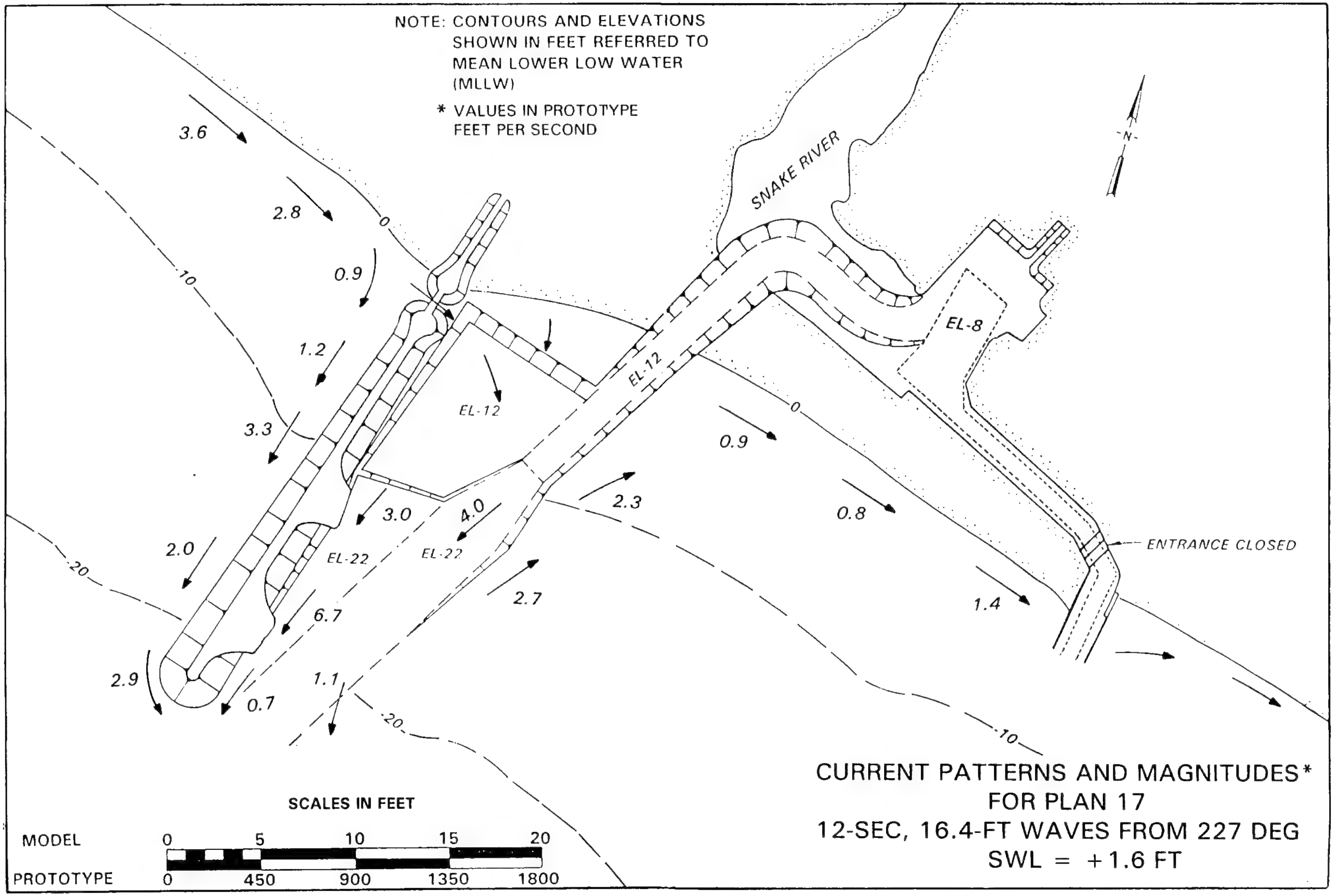
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
9-SEC, 6.6-FT WAVES FROM 227 DEG
SWL = +1.6 FT



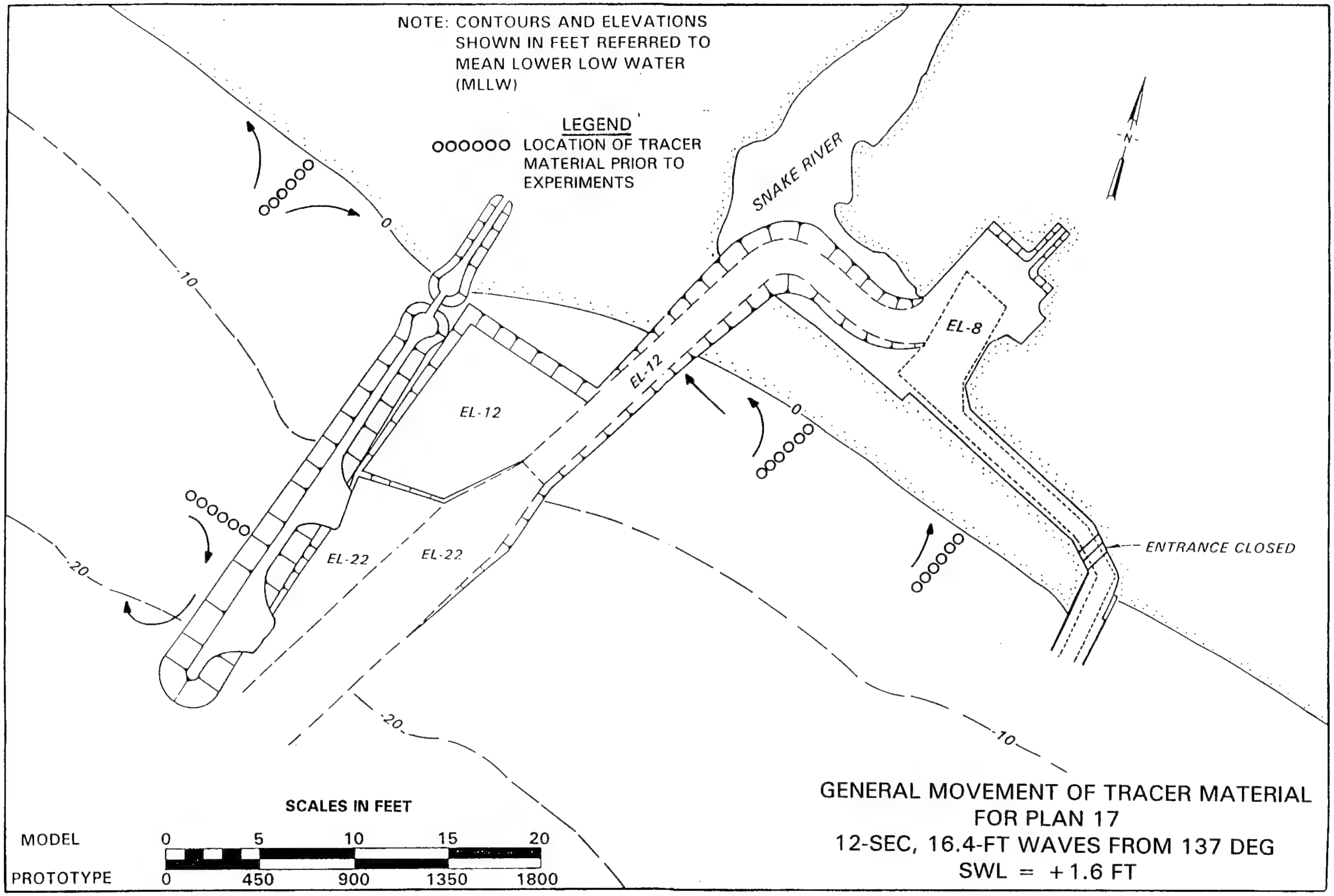
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 3.3-FT WAVES FROM 227 DEG
SWL = +1.6 FT



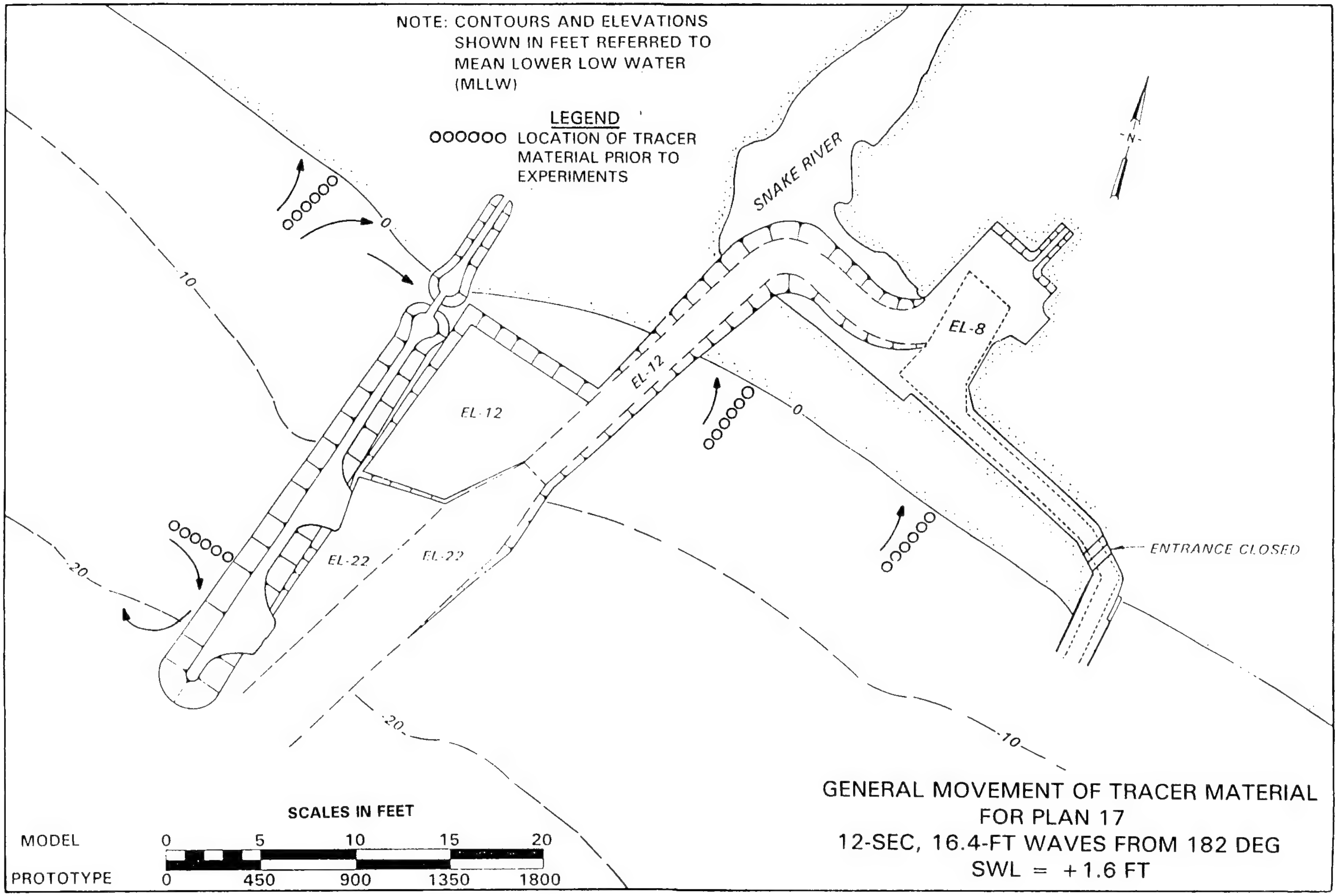
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 6.6-FT WAVES FROM 227 DEG
SWL = +1.6 FT



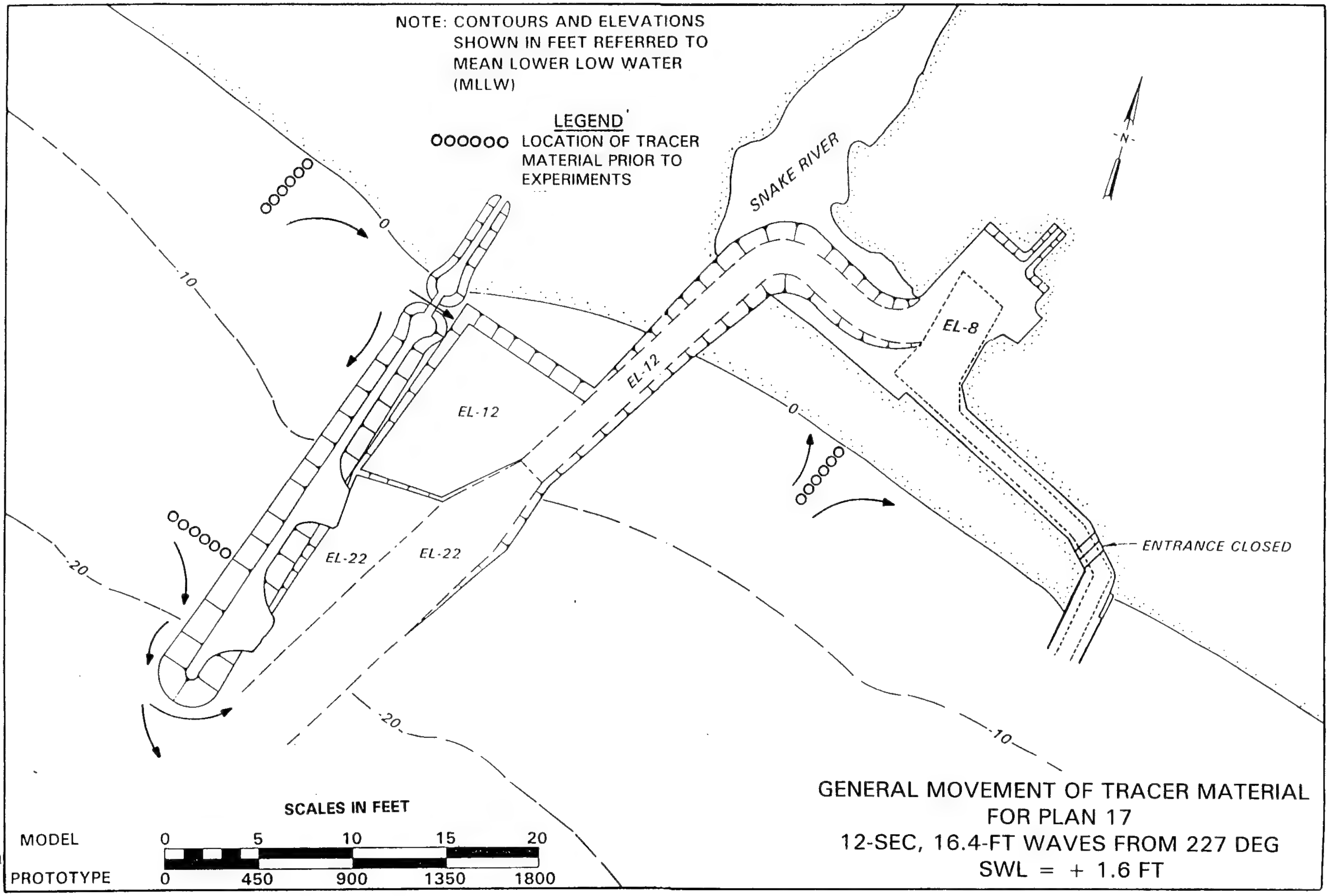
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 17
12-SEC, 16.4-FT WAVES FROM 227 DEG
SWL = +1.6 FT



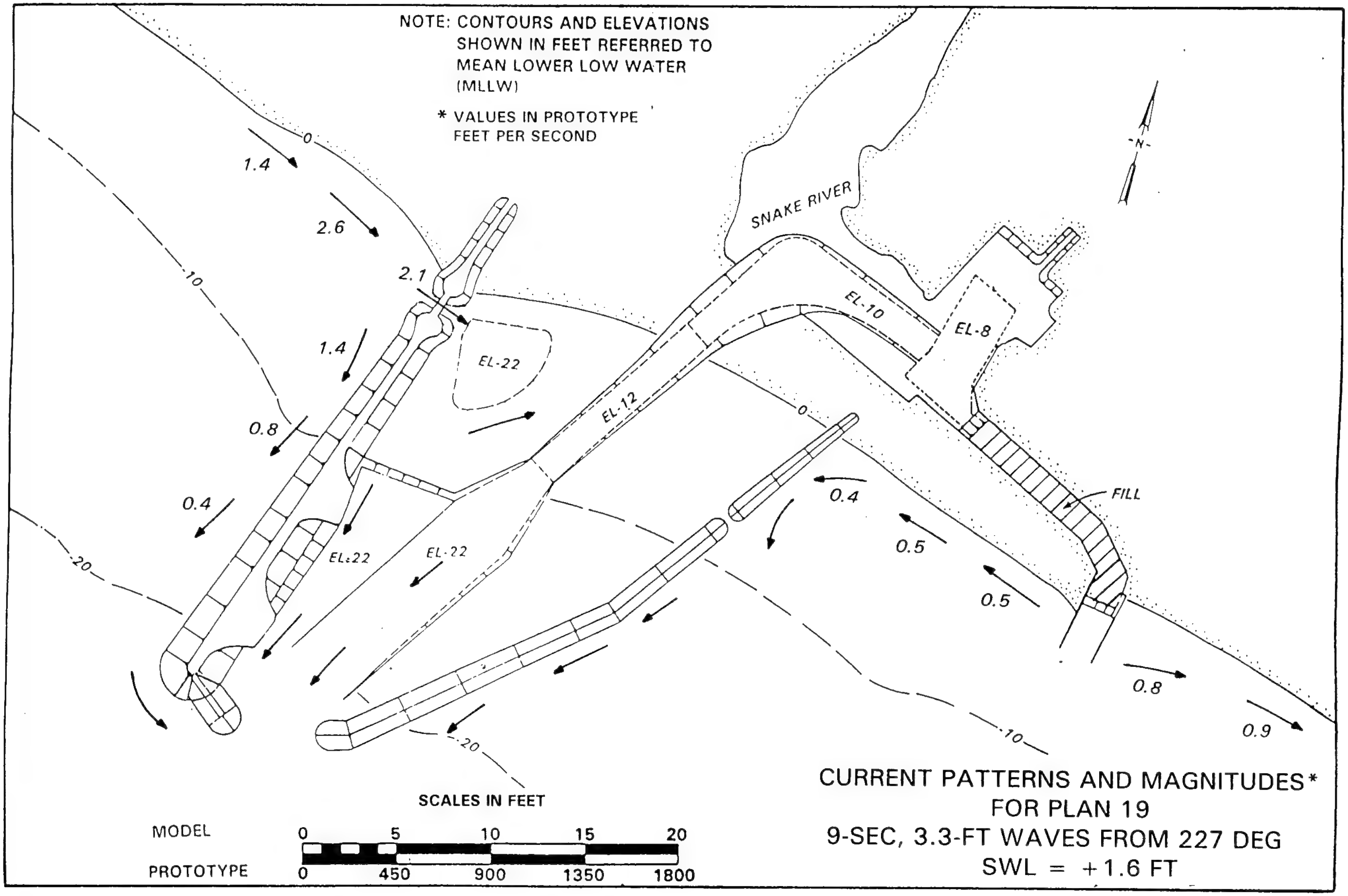
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 17
12-SEC, 16.4-FT WAVES FROM 137 DEG
SWL = +1.6 FT



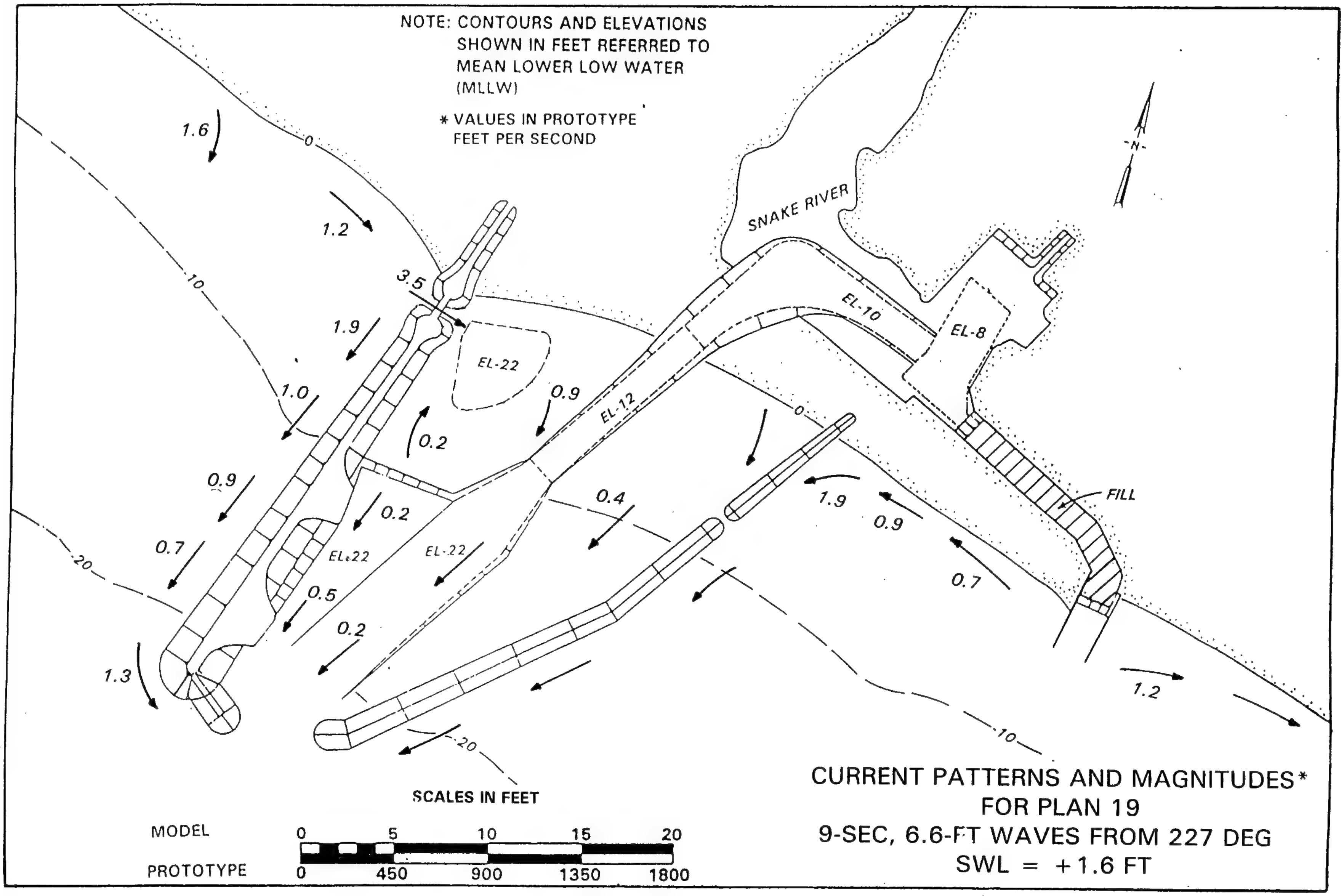
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 17
12-SEC, 16.4-FT WAVES FROM 182 DEG
SWL = +1.6 FT



GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 17
12-SEC, 16.4-FT WAVES FROM 227 DEG
SWL = + 1.6 FT



CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
9-SEC, 3.3-FT WAVES FROM 227 DEG
SWL = +1.6 FT



CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
9-SEC, 6.6-FT WAVES FROM 227 DEG
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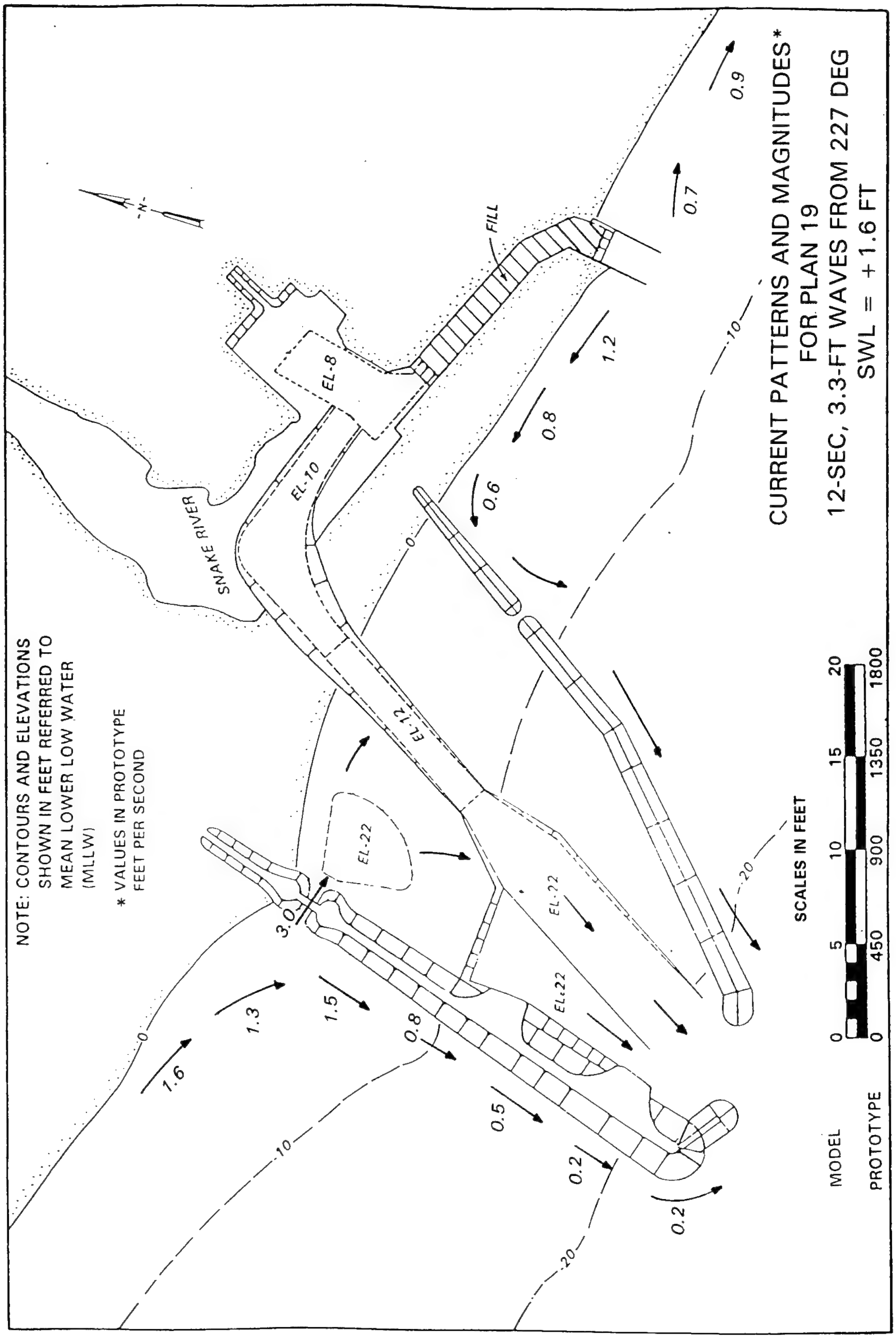
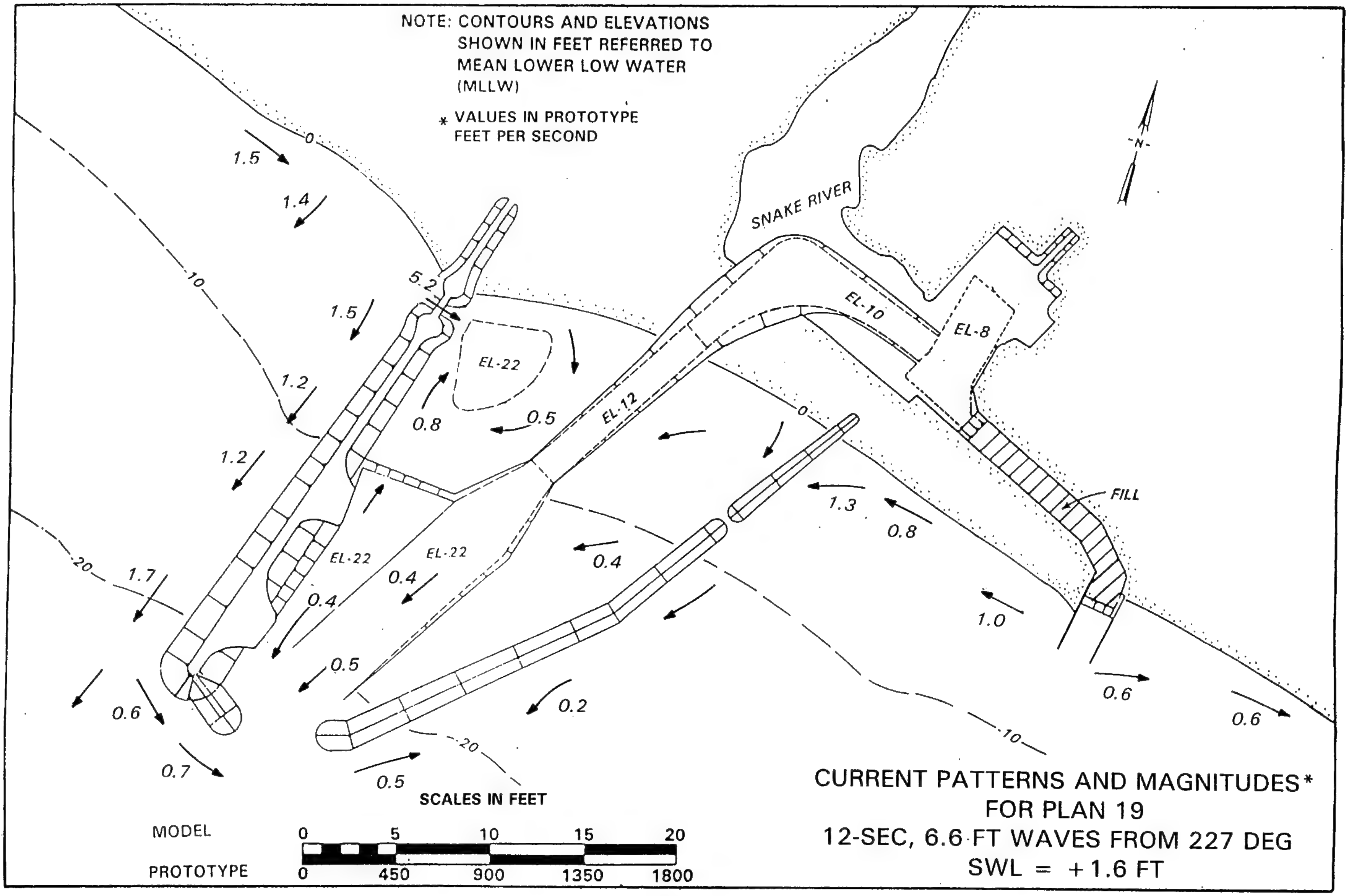


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
12-SEC, 3.3-FT WAVES FROM 227 DEG
SWL = +1.6 FT
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
* VALUES IN PROTOTYPE FEET PER SECOND
SNAKE RIVER
FILL
EL-8
EL-10
EL-12
EL-22
EL-22
EL-22
N
0.9
0.7
1.2
0.8
0.6
3.0
1.3
1.5
1.6
0.8
0.5
0.2
0.2
0
10
20
SCALES IN FEET
MODEL 0 5 10 15 20
PROTOTYPE 0 450 900 1350 1800



CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
12-SEC, 6.6 FT WAVES FROM 227 DEG
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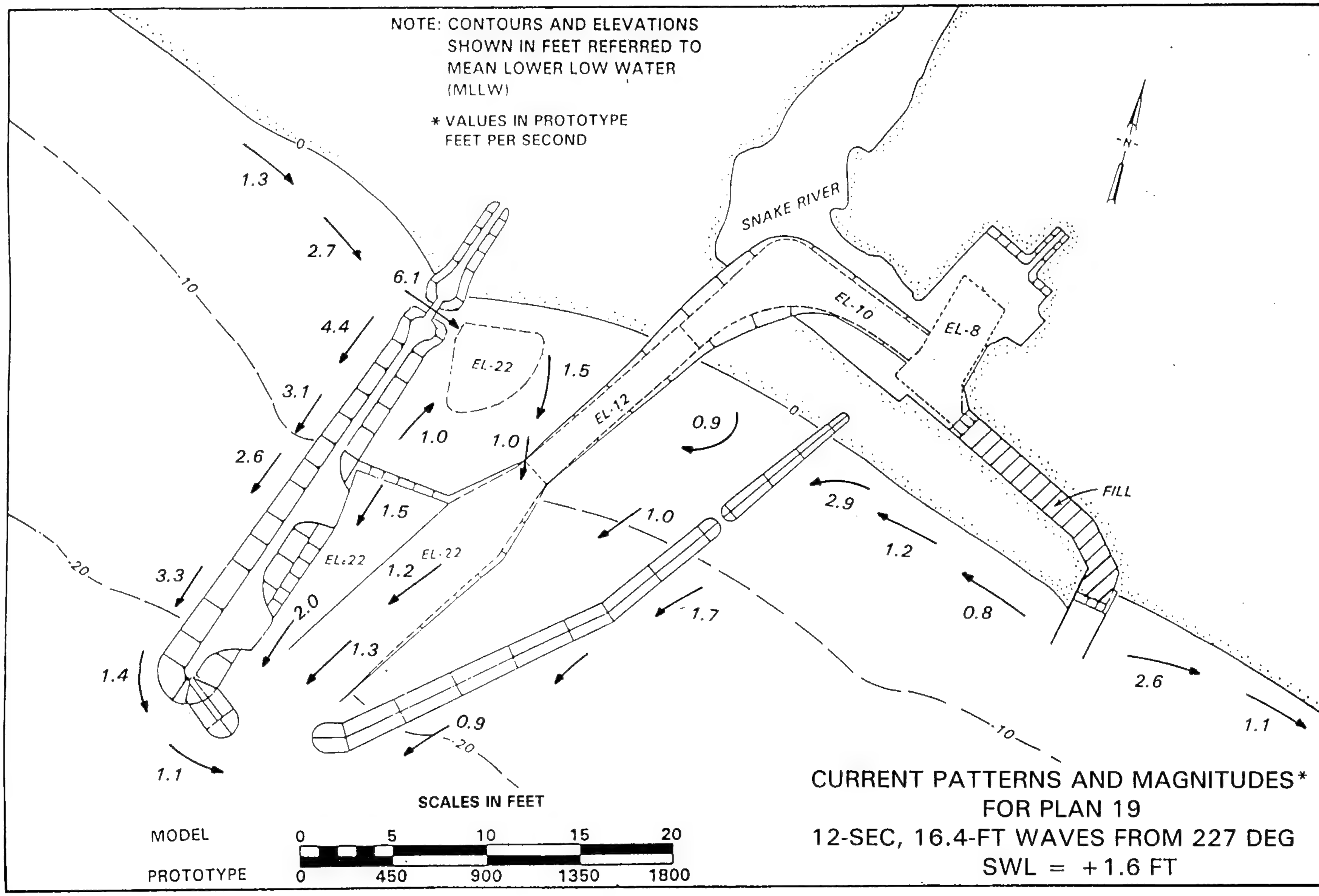
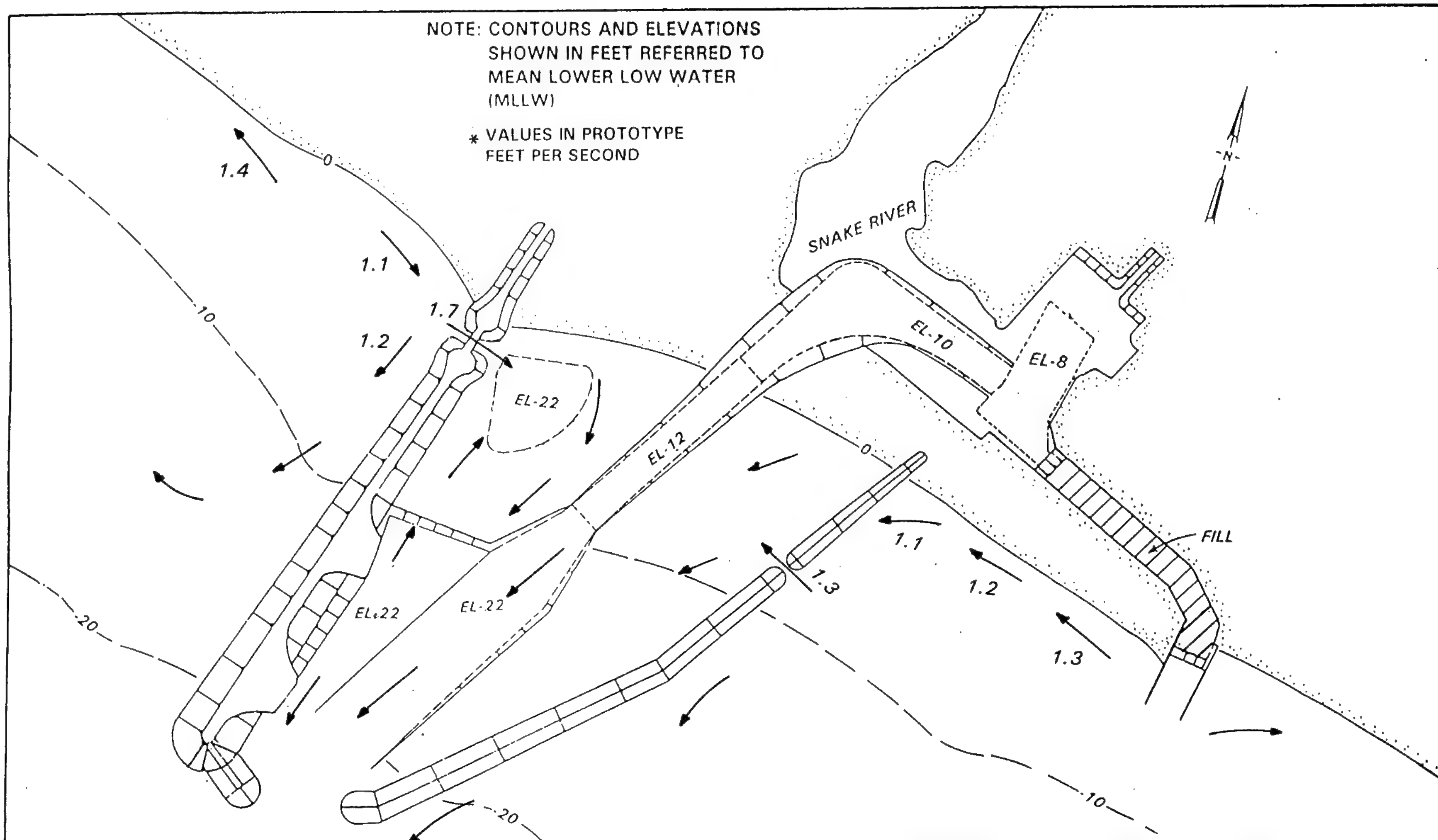
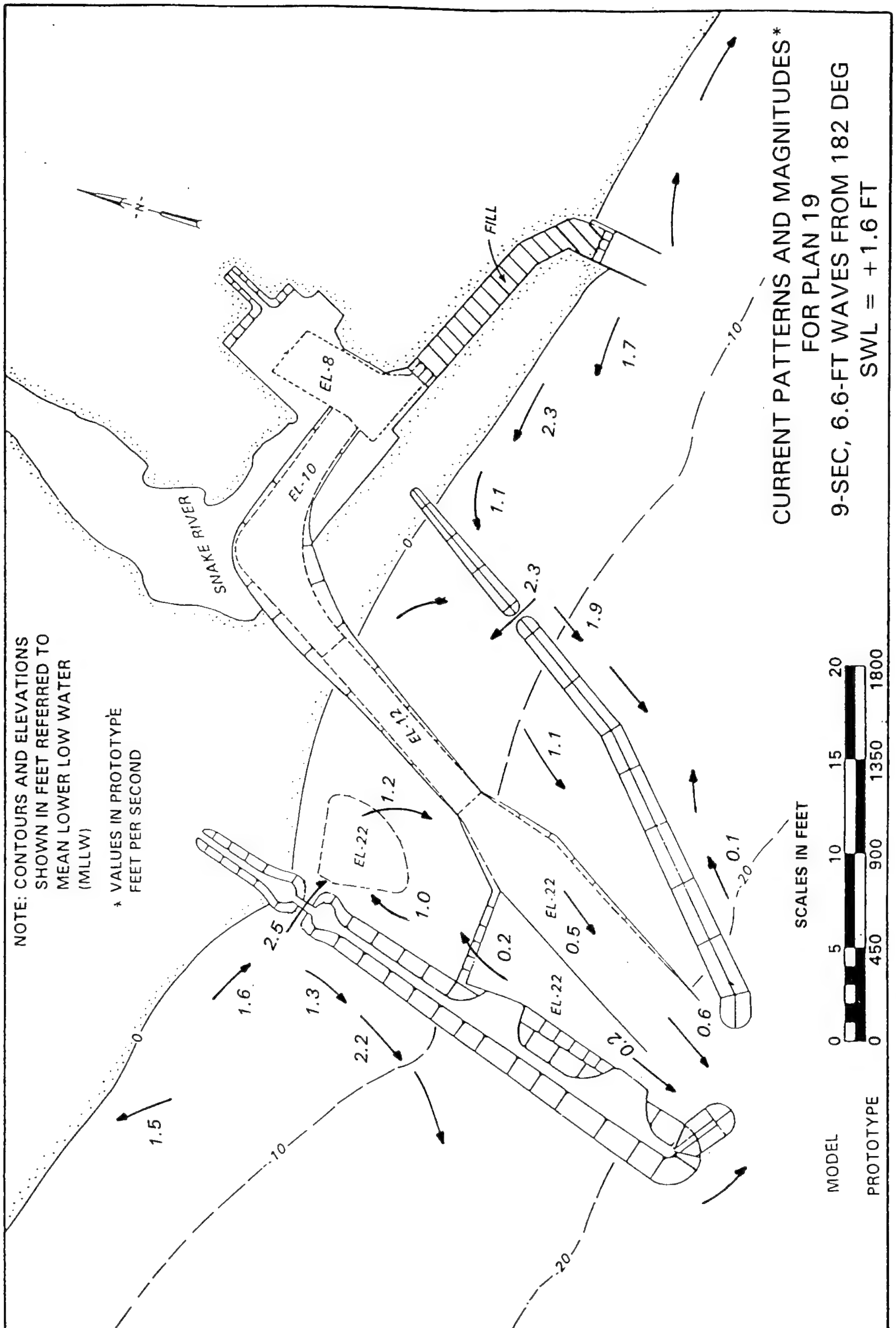


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
12-SEC, 16.4-FT WAVES FROM 227 DEG
SWL = +1.6 FT



CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
9-SEC, 3.3-FT WAVES FROM 182 DEG
SWL = +1.6 FT



CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
9-SEC, 6.6-FT WAVES FROM 182 DEG
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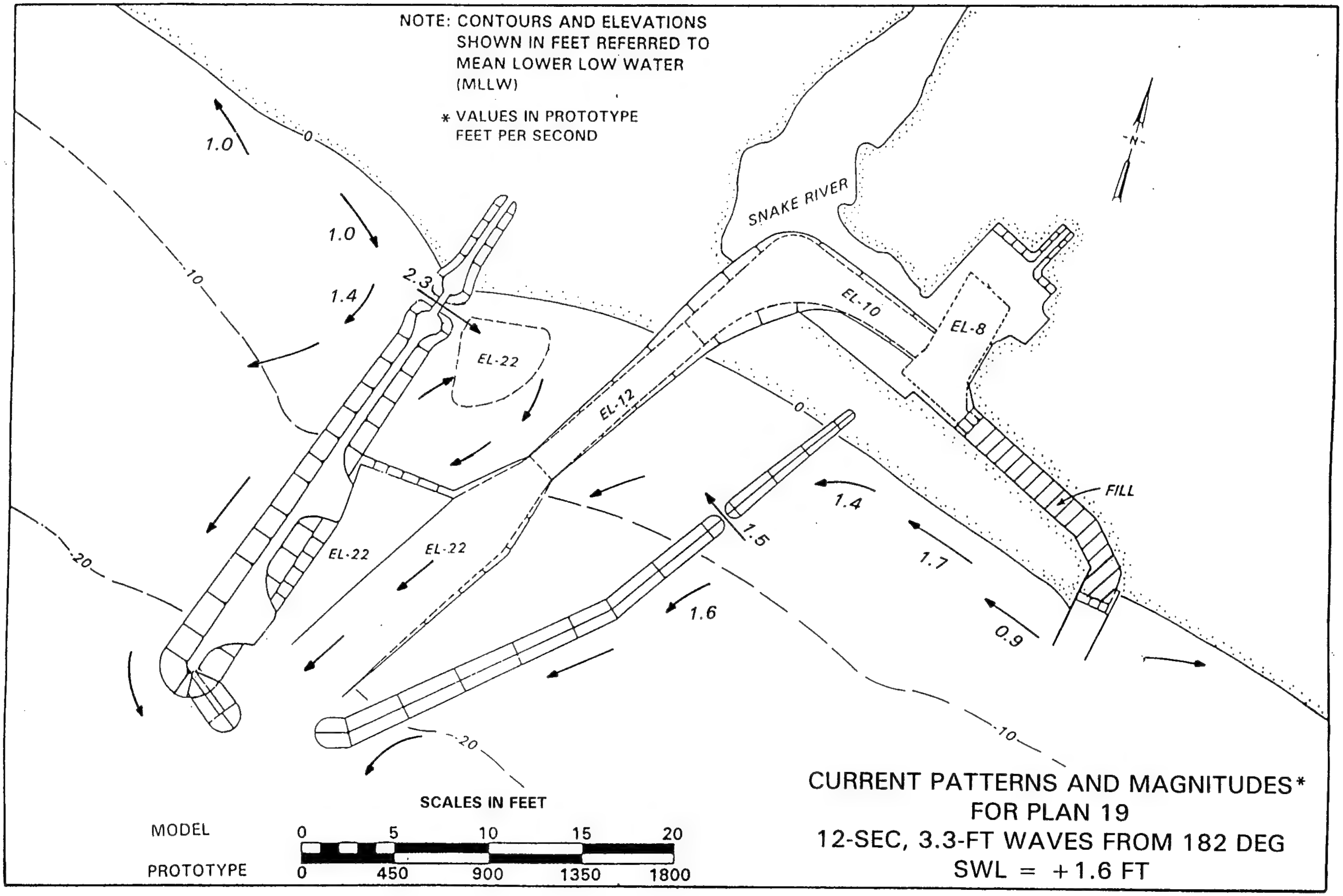
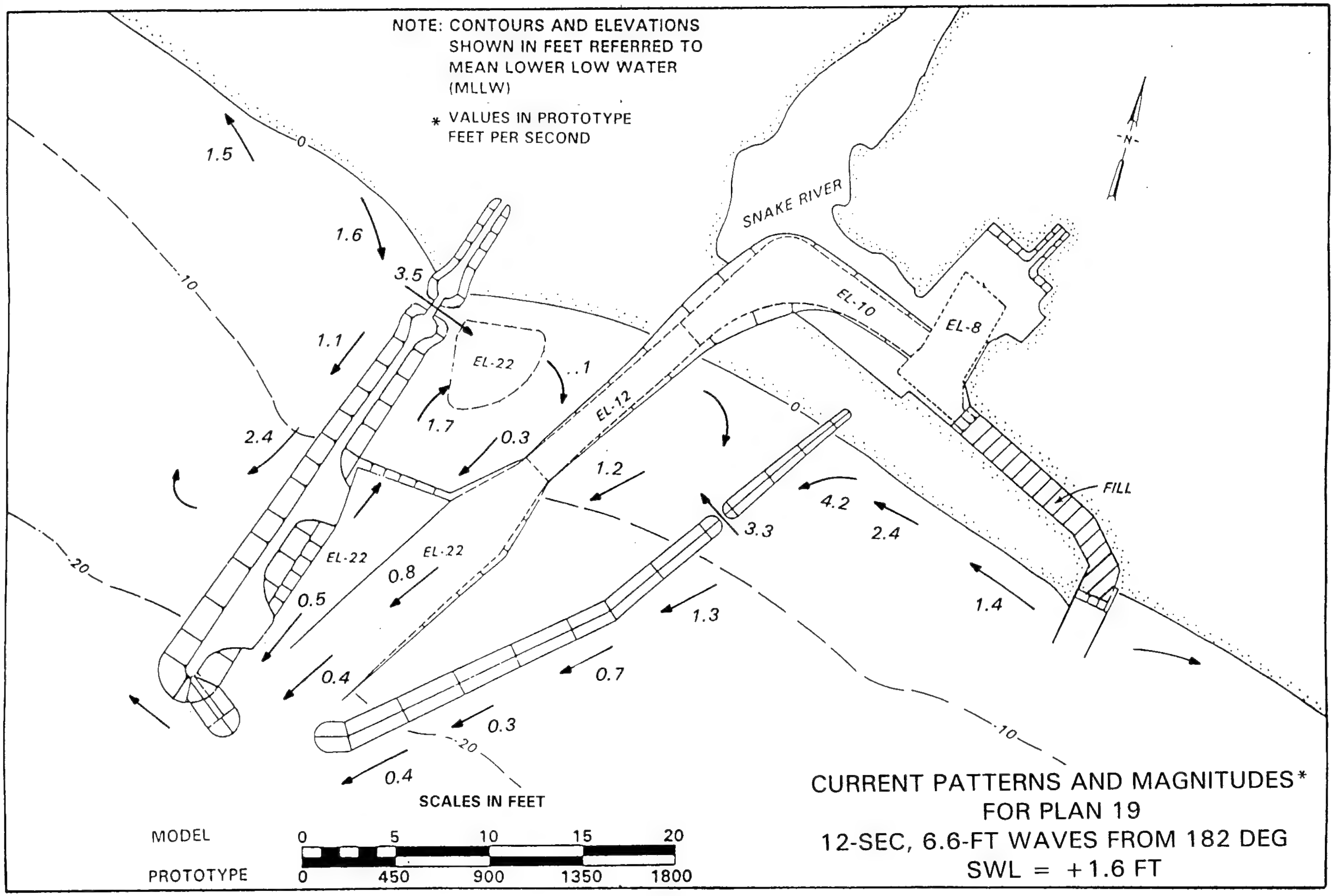


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
12-SEC, 3.3-FT WAVES FROM 182 DEG
SWL = +1.6 FT



CURRENT PATTERNS AND MAGNITUDES*
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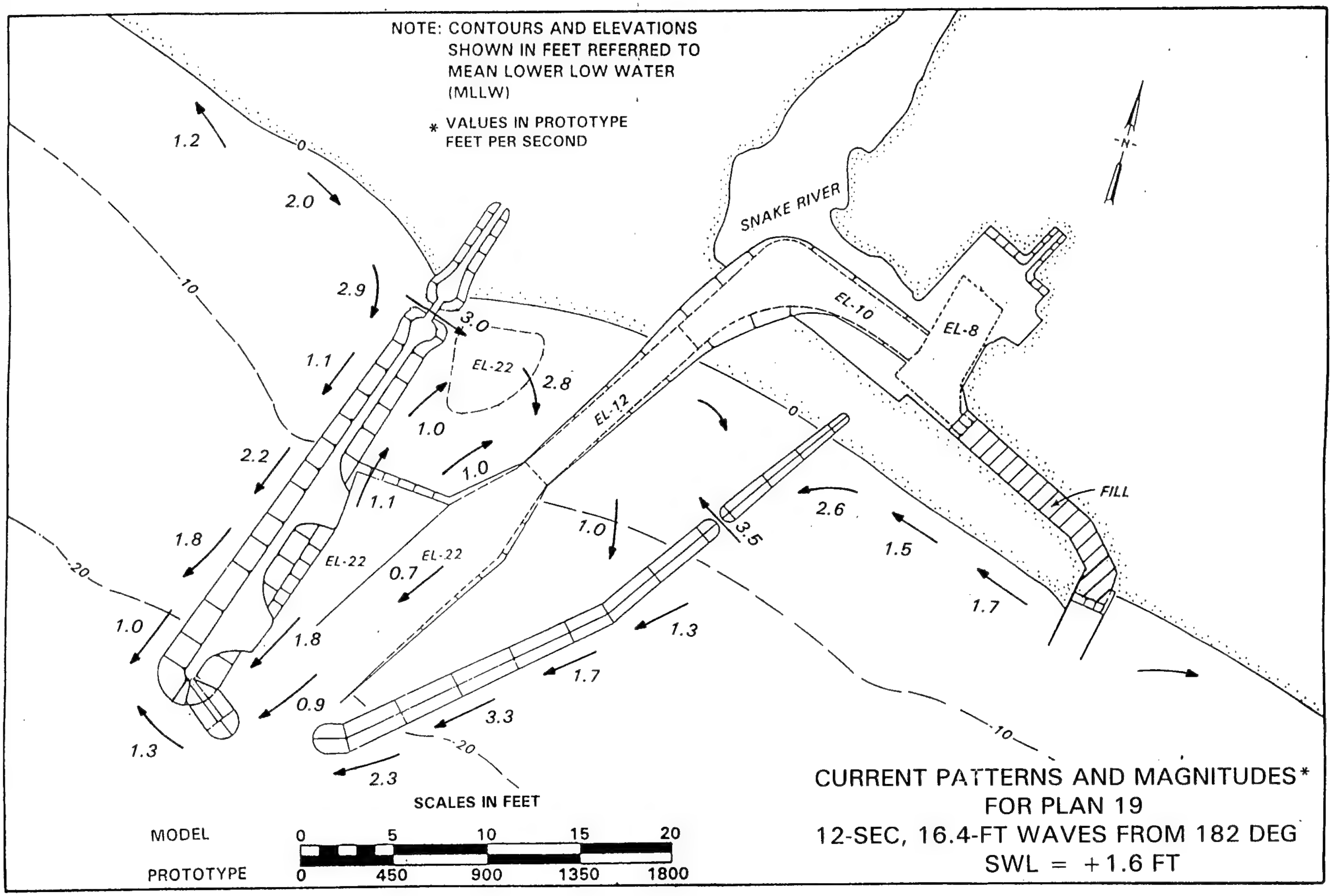

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12-SEC, 16.4-FT WAVES FROM 182 DEG
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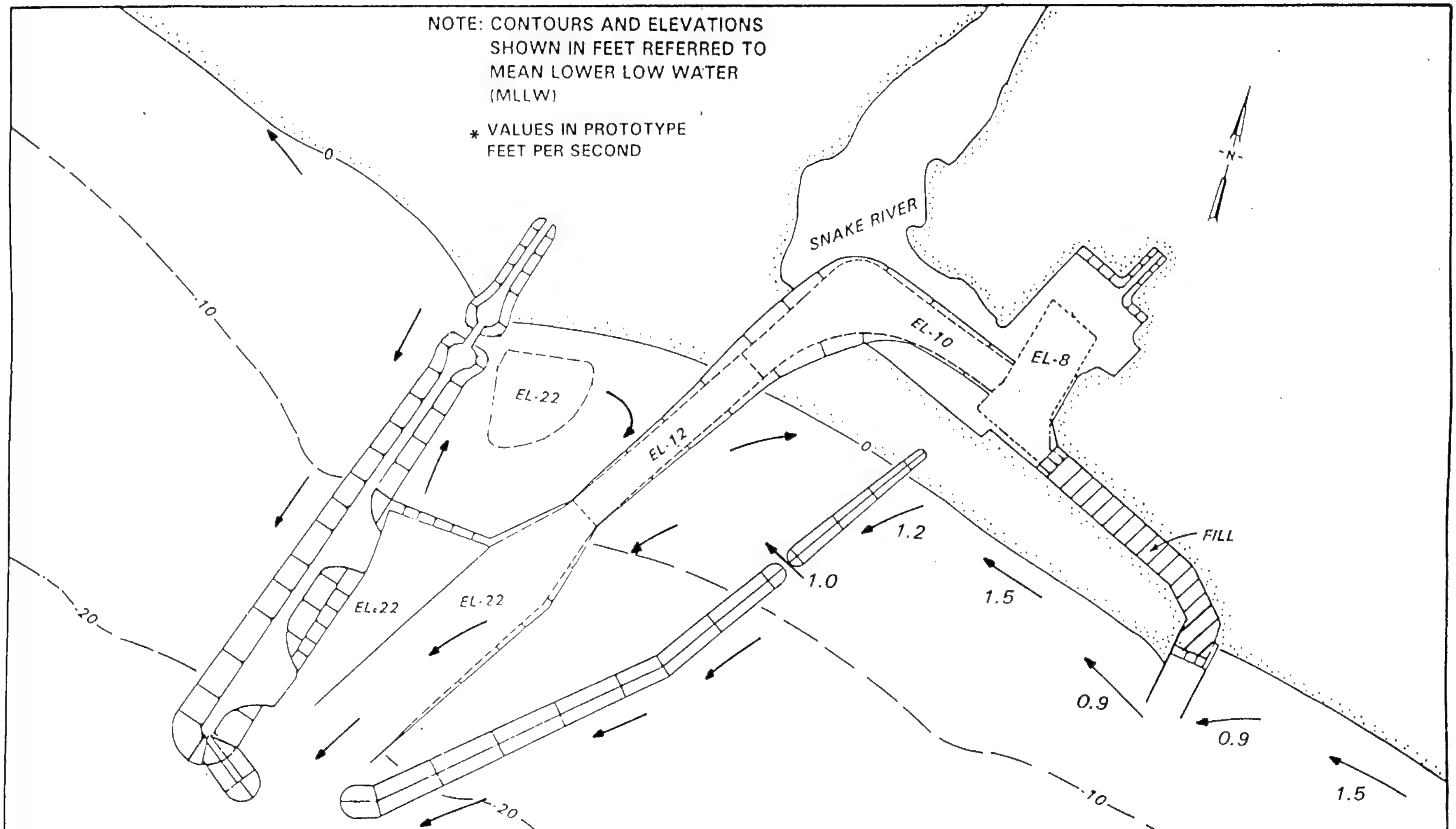
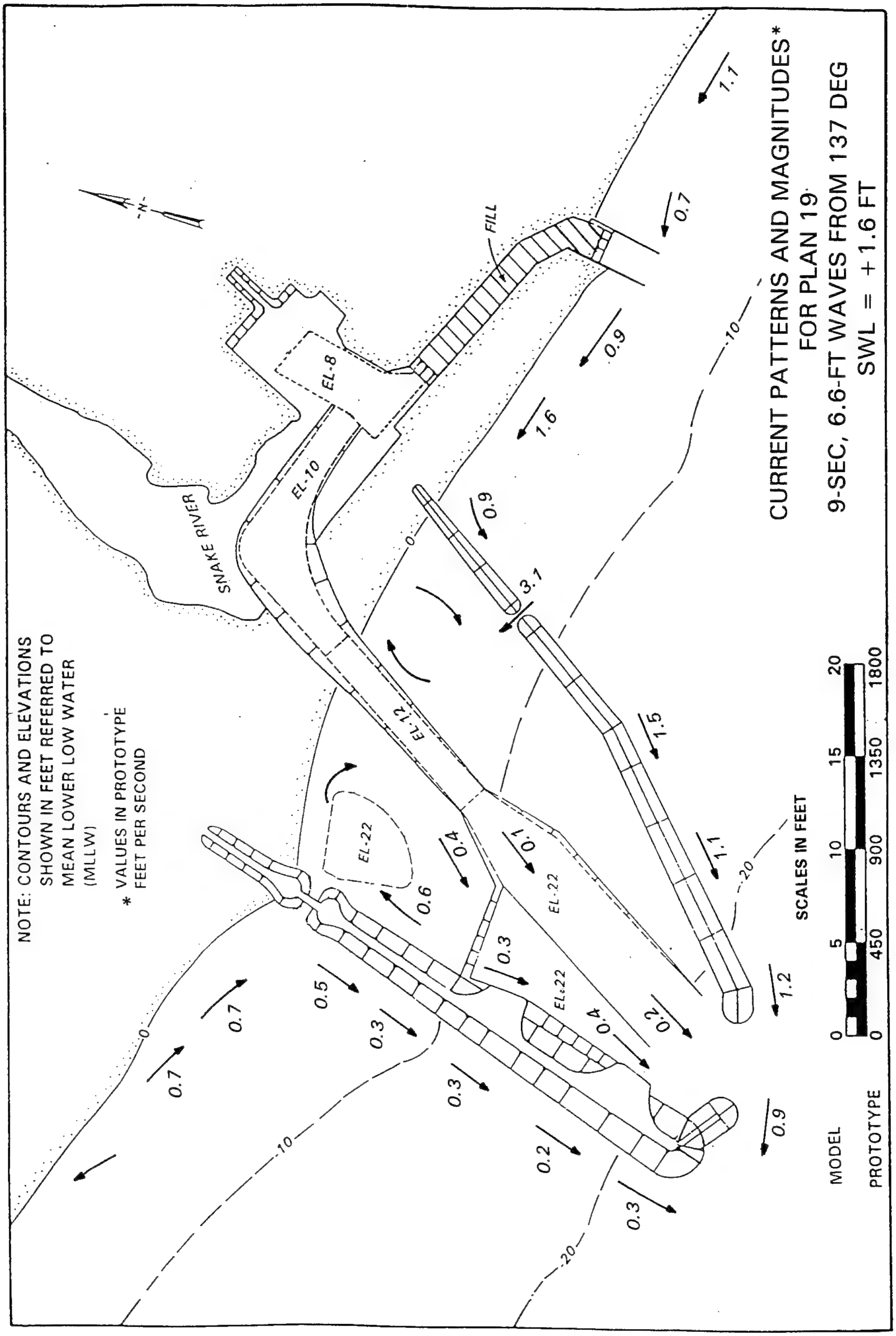


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
9-SEC, 3.3-FT WAVES FROM 137 DEG
SWL = +1.6 FT


CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
9-SEC, 6.6-FT WAVES FROM 137 DEG
SWL = +1.6 FT
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
* VALUES IN PROTOTYPE FEET PER SECOND
SNAKE RIVER
FILL
EL-8
EL-10
EL-12
EL-22
EL-22
EL-22
N
SCALES IN FEET
MODEL
PROTOTYPE
0
5
10
15
20
0
450
900
1350
1800
1.1
0.7
0.9
1.6
0.9
3.1
1.5
1.1
1.2
0.9
0.4
0.1
0.6
0.3
0.4
0.2
0.7
0.7
0.5
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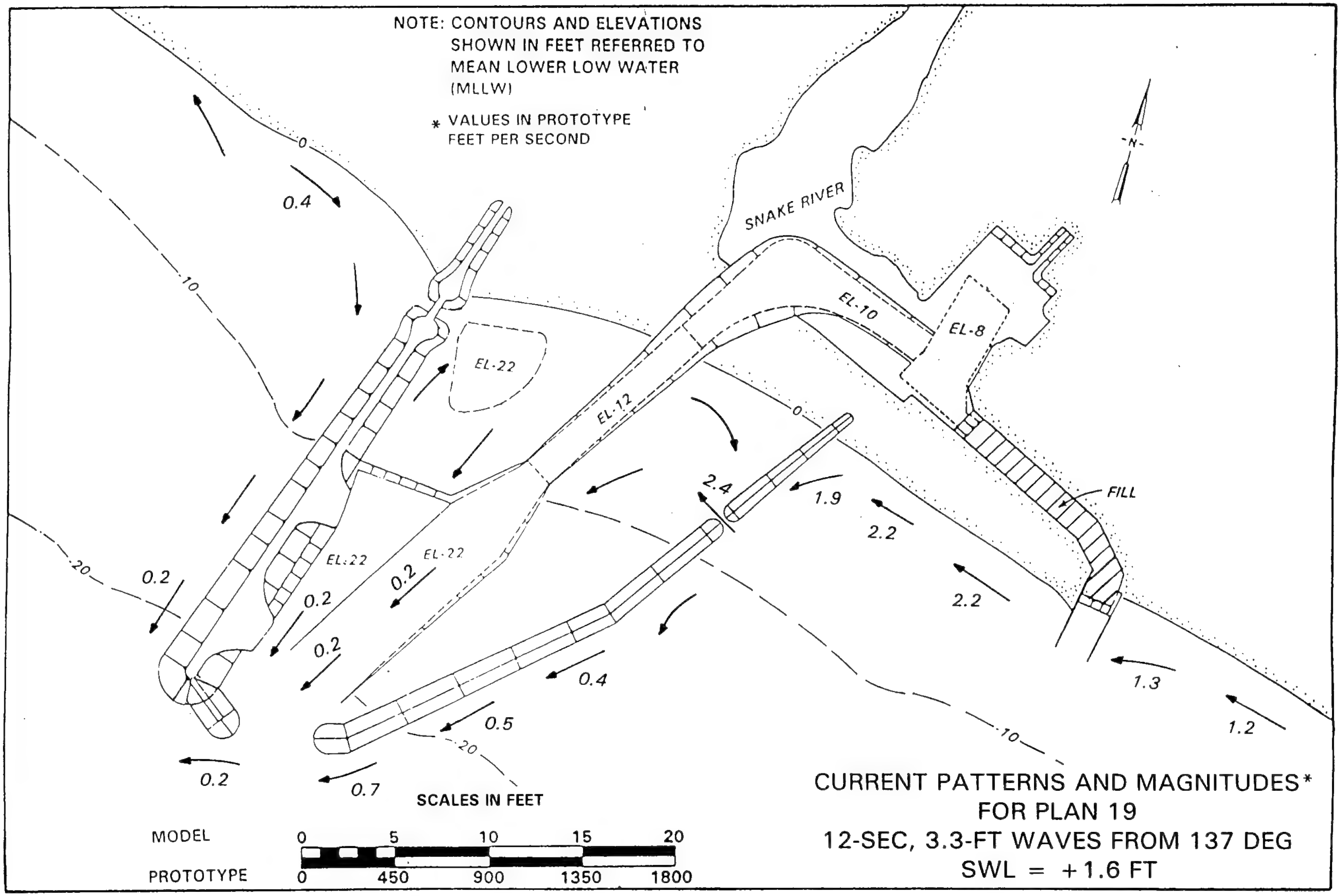
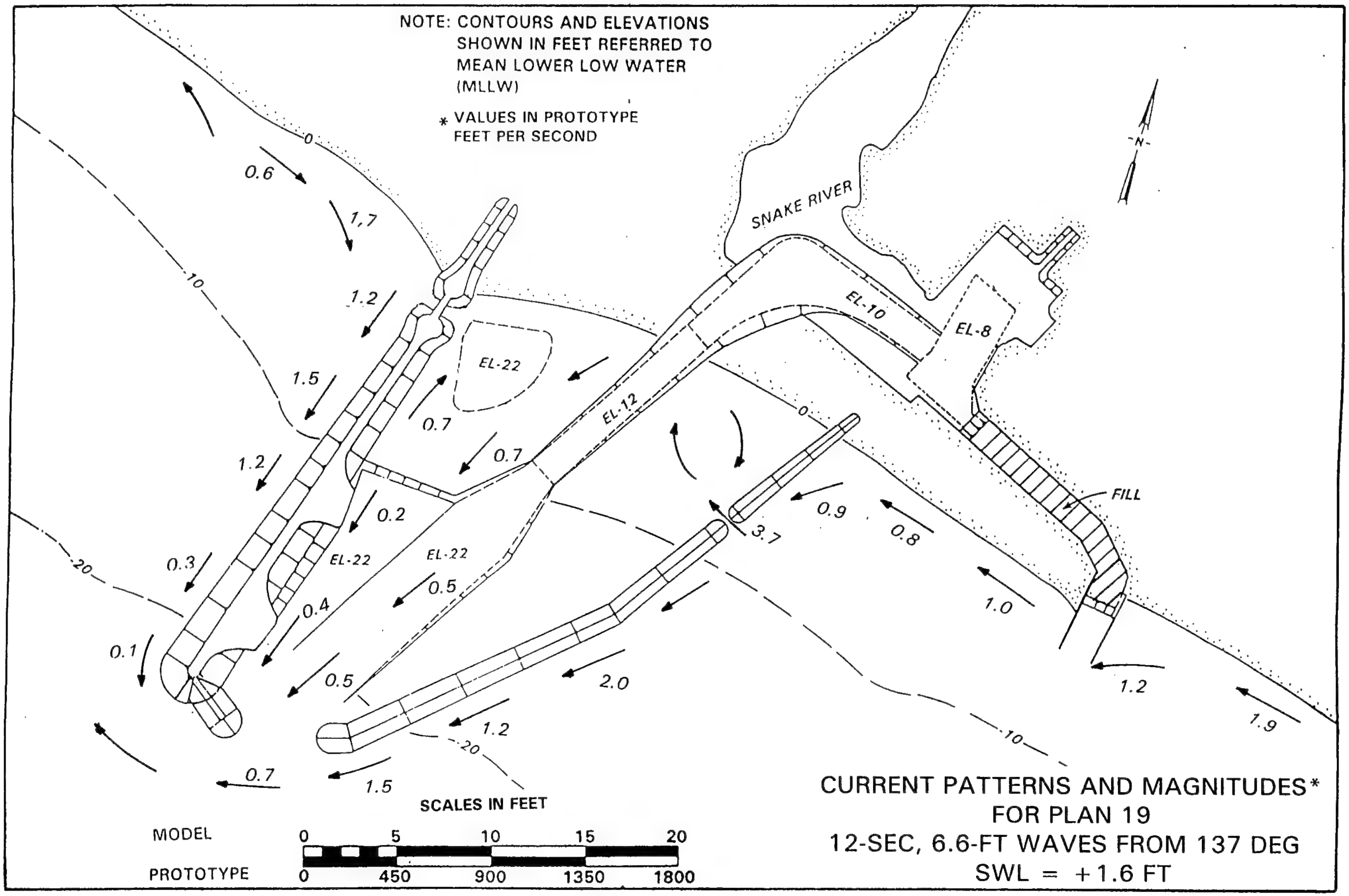
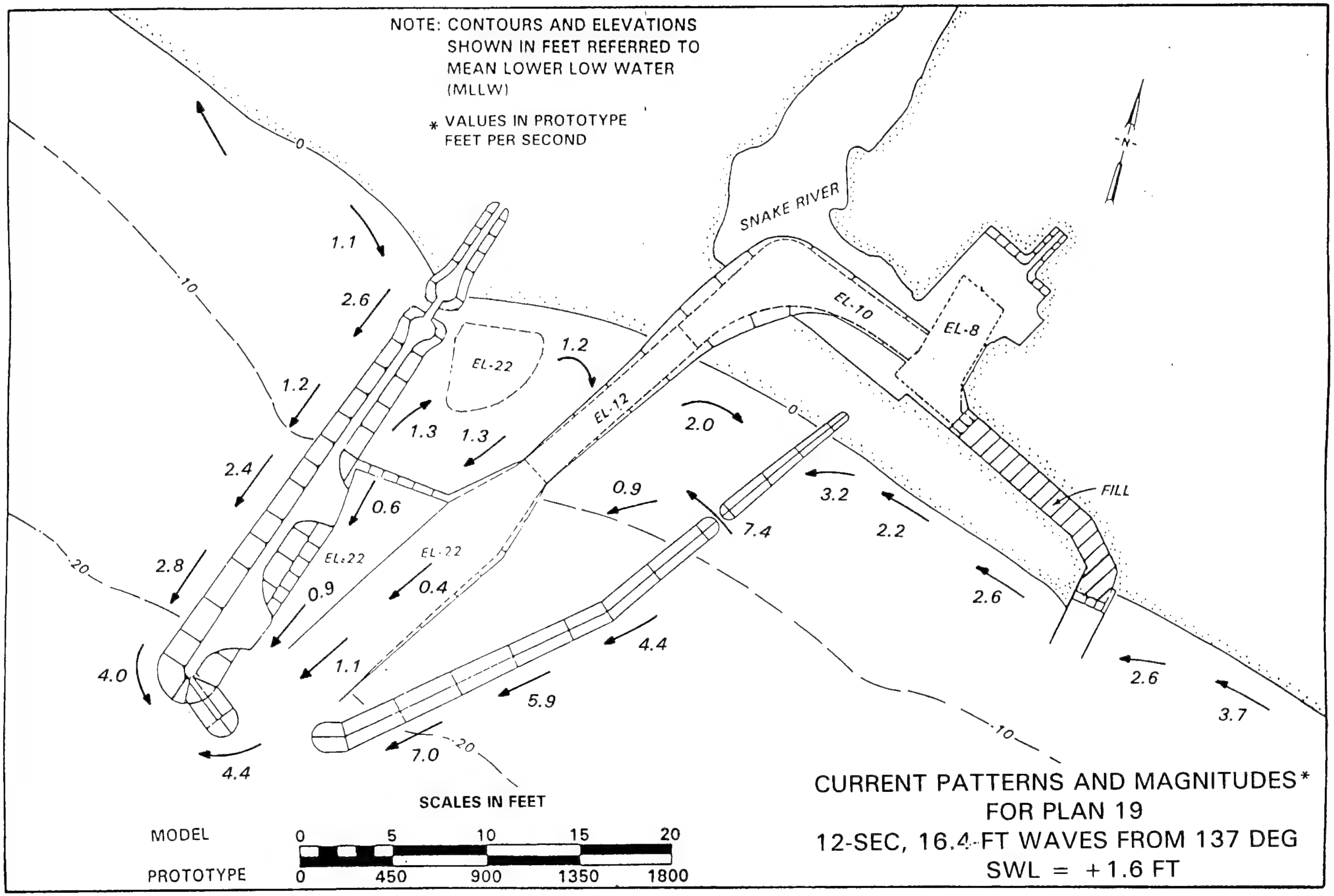
0.3
0.2
0.3



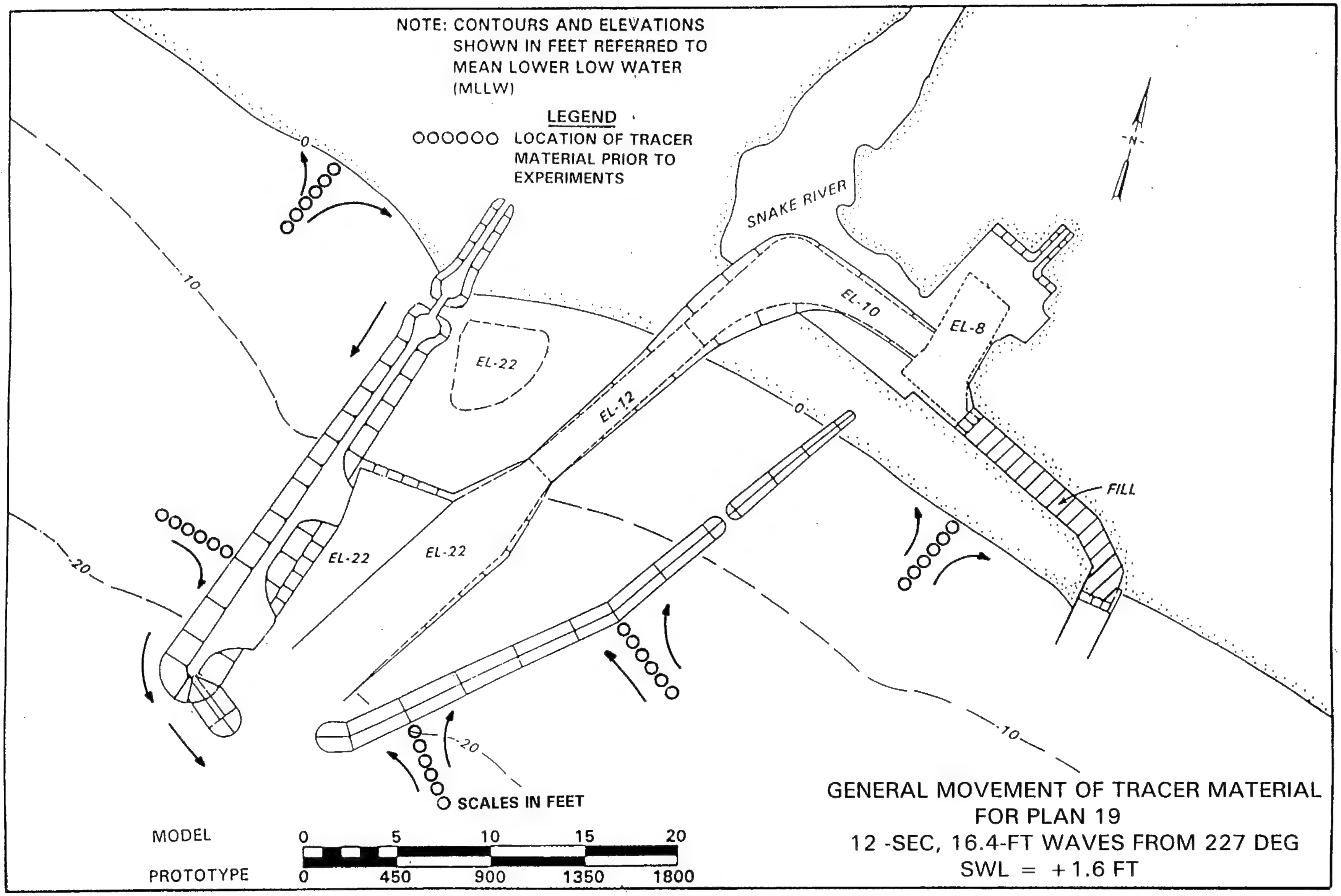
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
12-SEC, 3.3-FT WAVES FROM 137 DEG
SWL = +1.6 FT



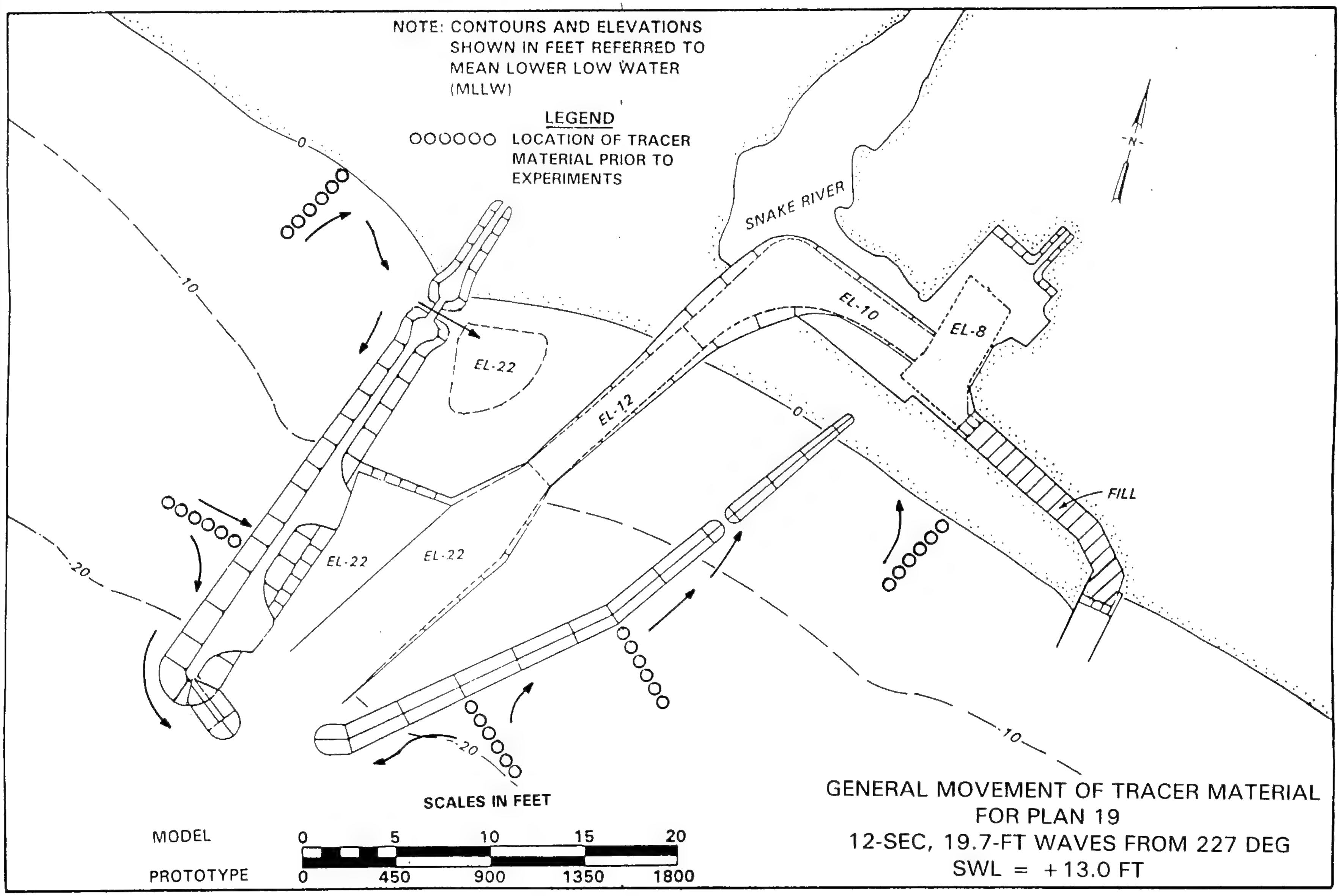
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
12-SEC, 6.6-FT WAVES FROM 137 DEG
SWL = +1.6 FT



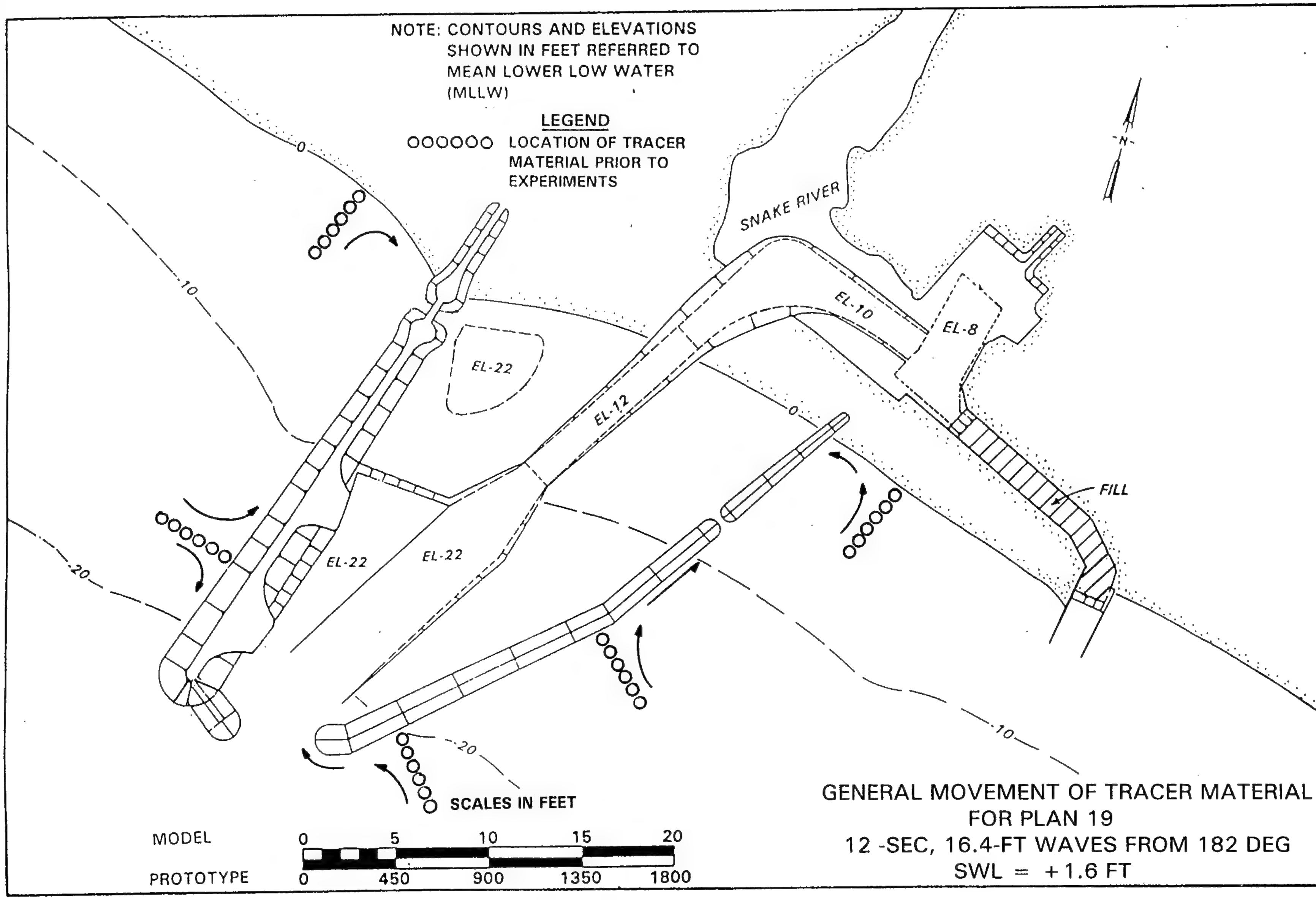
CURRENT PATTERNS AND MAGNITUDES*
FOR PLAN 19
12-SEC, 16.4-FT WAVES FROM 137 DEG
SWL = +1.6 FT



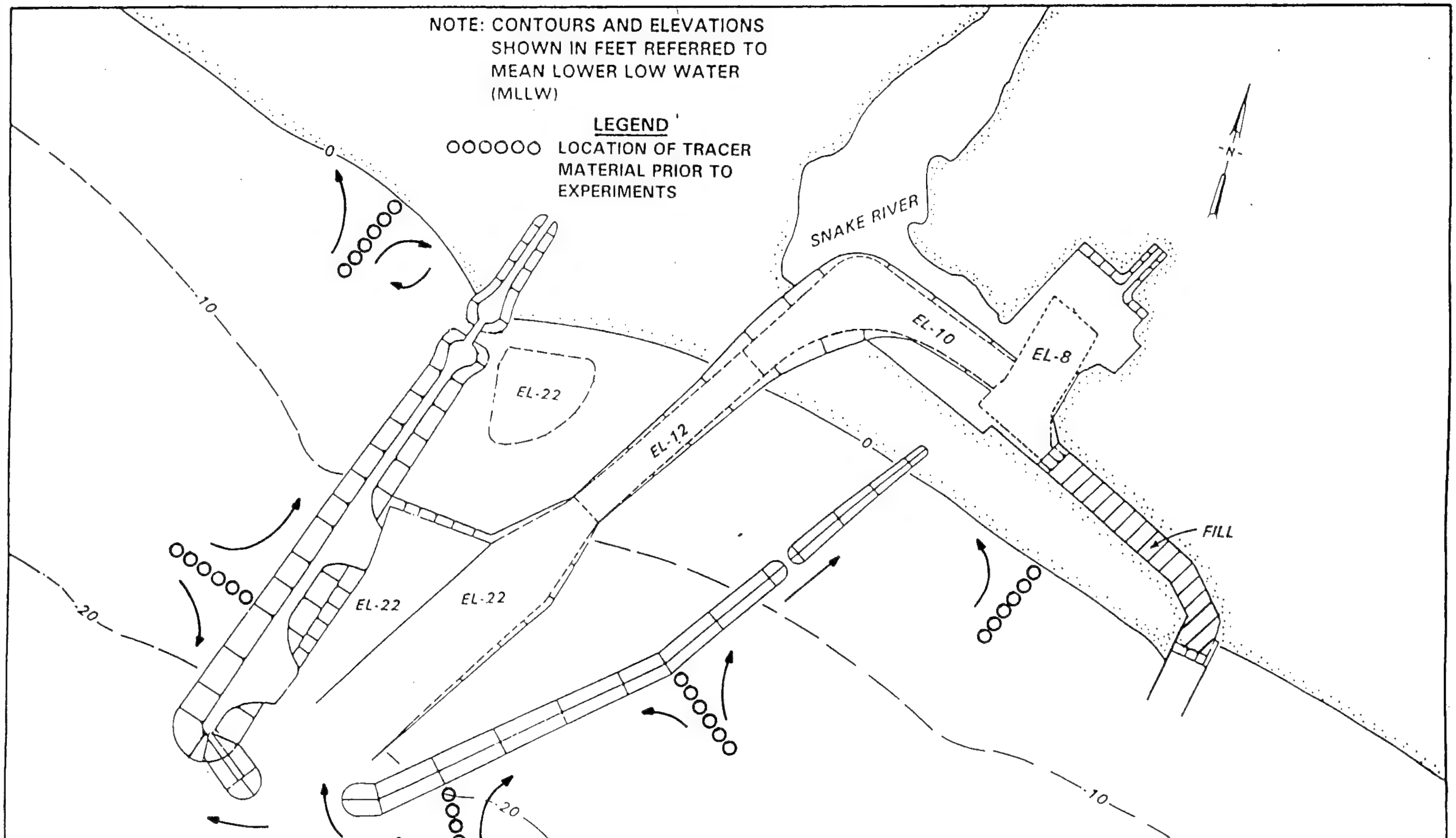
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 19
12 -SEC, 16.4-FT WAVES FROM 227 DEG
SWL = +1.6 FT



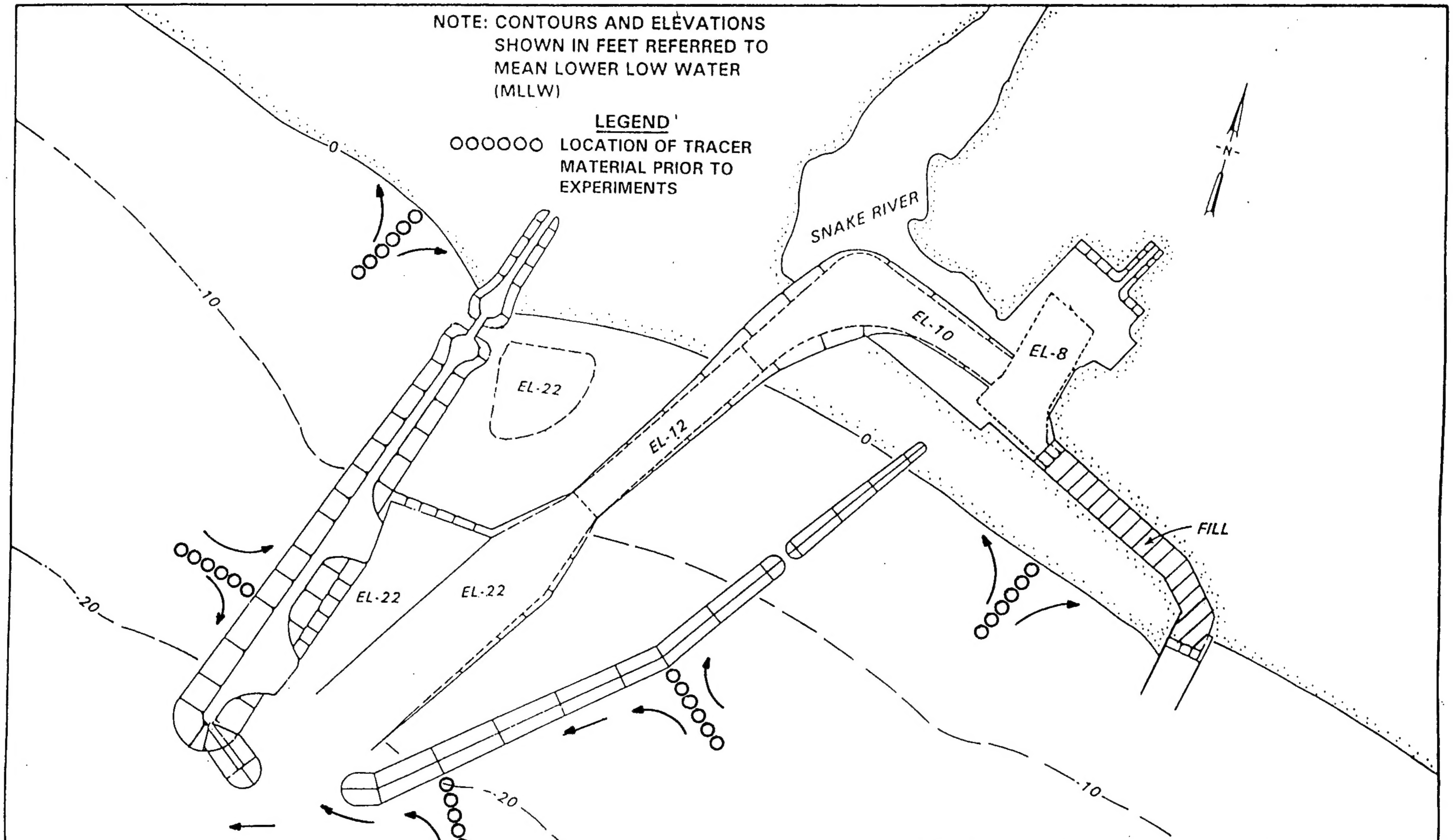
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 19
12-SEC, 19.7-FT WAVES FROM 227 DEG
SWL = +13.0 FT



GENERAL MOVEMENT OF TRACER MATERIAL FOR PLAN 19
12 -SEC, 16.4-FT WAVES FROM 182 DEG
SWL = +1.6 FT



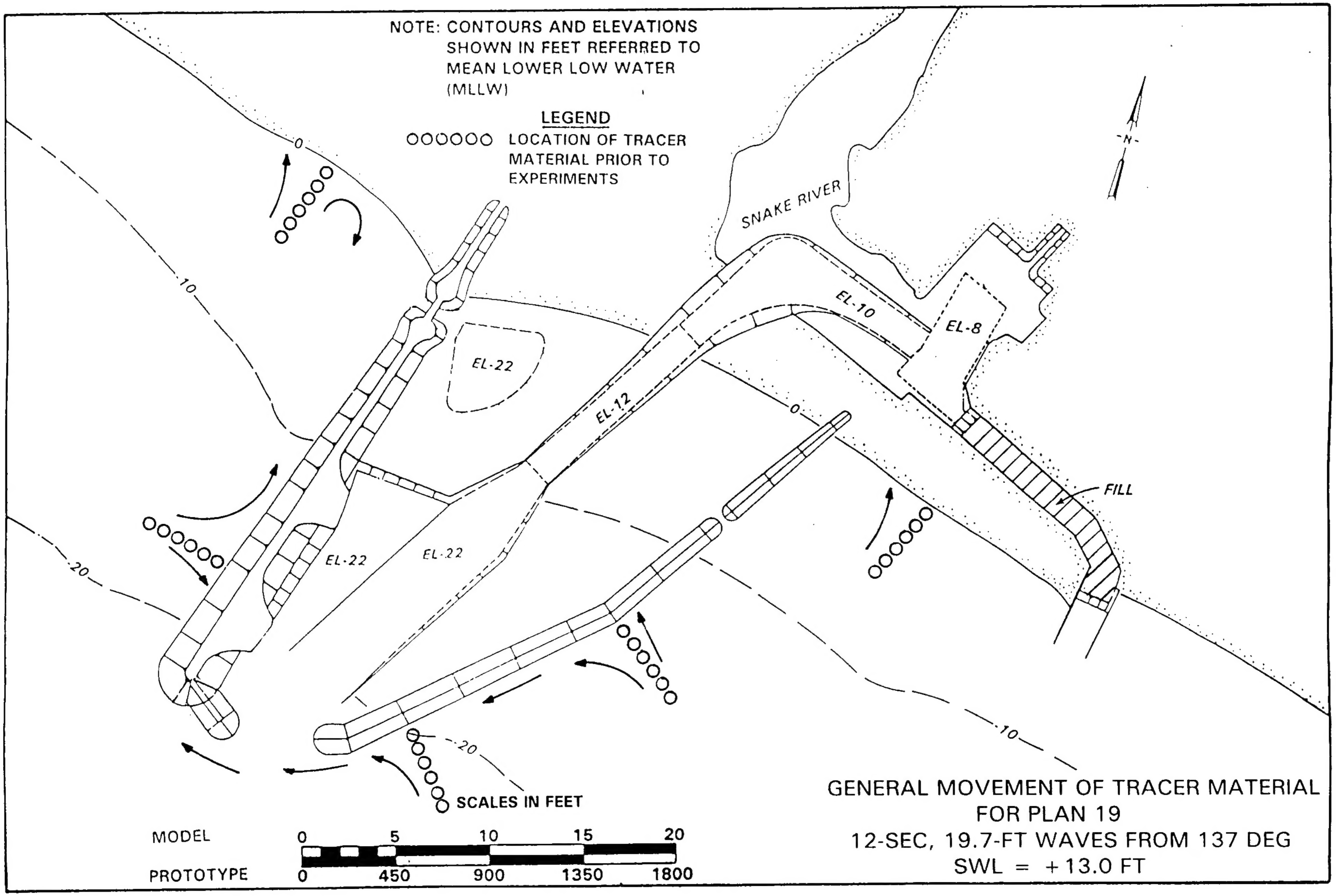
GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 19
12 SEC, 19.7-FT WAVES FROM 182 DEG
SWL = +13.0 FT



GENERAL MOVEMENT OF TRACER MATERIAL FOR PLAN 19

12 -SEC, 16.4-FT WAVES FROM 137 DEG

SWL = +1.6 FT



GENERAL MOVEMENT OF TRACER MATERIAL
FOR PLAN 19
12-SEC, 19.7-FT WAVES FROM 137 DEG
SWL = +13.0 FT

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1998

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Design for Navigation Improvements at Nome Harbor, Alaska; Coastal Model Investigation

5. FUNDING NUMBERS

6. AUTHOR(S)
Robert R. Bottin, Jr., Hugh F. Acuff

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report CHL-98-28

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Alaska
P.O. Box 898
Anchorage, AK 99506-0898

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A 1:90-scale (undistorted) three-dimensional coastal hydraulic model was used to investigate the design of proposed navigation improvements at Nome Harbor, Alaska, with respect to wave, current, and shoaling conditions at the site. The model reproduced about 3,350 m (11,000 ft) of the Alaskan shoreline, the existing harbor and lower reaches of the Snake River, and sufficient offshore bathymetry in the Norton Sound to permit generation of the required experimental waves. The model was used to determine the impacts of a new entrance channel on wave-induced current patterns and magnitudes, sediment transport patterns, and wave conditions in the new channel and harbor area, as well as to optimize the lengths and alignments of new breakwaters and causeway extensions. A 24.4-m-long (90-ft-long) unidirectional, spectral wave generator, and automated data acquisition and control system, and a crushed coal tracer material were utilized in model operation. It was concluded from study results that:

a. Existing conditions are characterized by rough and turbulent wave conditions in the existing entrance. Very confused wave patterns were observed in the entrance due to wave energy reflected off the vertical walls lining the entrance. Wave heights in excess of 1.5 m (5 ft) were obtained in the entrance for typical storm conditions; and wave heights of almost 3.7 m (12 ft) were obtained in the entrance for 50-year storm wave conditions with extreme high-water level (4 m (+13 ft)).

b. Wave conditions along the vertical-faced causeway docks were excessive for existing conditions. Wave heights in excess of 3.7 and 2.7 m (12 and 9 ft) were obtained along the outer and inner docks, respectively, for typical storm conditions; and wave heights of almost 7 and 5.8 m (23 and 19 ft) were recorded along these docks, respectively, for 50-year storm wave conditions with extreme high-water levels.

(Continued)

14. SUBJECT TERMS

Breakwaters	Navigation	Wave protection
Causeways	Nome Harbor, Alaska	
Harbors, Alaska	Sediment transport patterns	
Hydraulic models	Wave-induced currents	

15. NUMBER OF PAGES
153

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

c. Preliminary experiments provided an excellent means to expeditiously evaluate various improvement plans (Plans 1-18) with respect to wave heights, wave-induced current patterns and magnitudes, and sediment tracer patterns and subsequent deposits. These experimental results were used as a basis for development of the final improvement plan (Plan 19).

d. The final improvement plan (Plan 19) will result in calm conditions (wave heights of 0.15 m (0.5 ft) or less) in the existing harbor during typical storm conditions. For 50-year storm conditions with extreme high-water levels, wave heights will not exceed 0.52 m (1.7 ft) in the harbor.

e. Wave heights at the causeway docks, particularly the inner dock, will be significantly reduced as result as a result of the Plan 19 breakwater configuration during both typical and extreme (50-year) storm wave events.

f. The Plan 19 breakwater configuration will have no adverse impacts on current patterns and magnitudes and/or the movement of sediment in the immediate area.

g. The widened and deepened breach in the existing causeway, in conjunction with the deposition basin of Plan 19, will be effective in trapping sediment (particularly for storm waves with higher swl's) for sand management purposes.